REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 074-0188

1. AGENCY USE ONLY (Leave blank)

2. REPORT DATE
27 June 1968

3. REPORT TYPE AND DATES COVERED
Master's Thesis August 1967 - June 1968

4. TITLE AND SUBTITLE
A SUGGESTED POLICY FOR INCORPORATING OPERATIONS RESEARCH / SYSTEMS ANALYSIS INTO THE INSTITUTE OF COMBINED ~~AND~~ ARMS AND SUPPORT'S MANAGEMENT MODEL

5. FUNDING NUMBERS

6. AUTHOR(S)
Ennis, Harry F., Major, USA

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

U.S. Army Command and General Staff
College
1 Reynolds Ave.
Fort Leavenworth, KS 66027

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES)

10. SPONSORING / MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION / AVAILABILITY STATEMENT
Approved for public release; distribution is unlimited.

12b. DISTRIBUTION CODE
A

13. ABSTRACT *(Maximum 200 Words)*
The Institute of Combined Arms and Support (ICAS), within the U.S. Army Combat Developments Command (USACDC), is responsible for developing the combat doctrine for forces that employ combined arms. In discharging its combat development responsibilities, ICAS is guided by a management model. To proceed through the development process various critical management/decision check points in this model must be passed. This study is directed to the incorporation of the techniques of Operations Research / Systems Analysis into the aforementioned model to provide the best decisions at the identified check points.

19991202 039

14. SUBJECT TERMS
ORSA; combined arms operations; Combat development; decision-making processes

15. NUMBER OF PAGES
149

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
U	U	U	A

NSN 7540-01-280-5500

Standard Form 298 (Rev. 2-89)
Prescribed by ANSI Std. Z39-18
298-102

A SUGGESTED POLICY FOR INCORPORATING OPERATIONS RESEARCH/SYSTEMS ANALYSIS INTO THE INSTITUTE OF COMBINED ARMS AND SUPPORT'S MANAGEMENT MODEL

A thesis presented to the Faculty of the U.S. Army Command and General Staff College in partial fulfillment of the requirements of the degree

MASTER OF MILITARY ART AND SCIENCE

by

HARRY F. ENNIS, MAJ, USA
B.S., Purdue University, 1958

Fort Leavenworth, Kansas
1968

THESIS APPROVAL PAGE

Name of Candidate HARRY F. ENNIS, MAJ, USA

Title of Thesis A Suggested Policy for Incorporating Operations Research/Systems Analysis into the Institute of Combined Arms and Support's Management Model

Approved by:

Elmer A. Yoetsch, LTC, SigC, Research and Thesis Monitor

Robert G. MacLennan, LTC, CE, Member, Graduate Faculty

____________________, Member, Graduate Faculty

Date 27 June 1968

The opinions and conclusions expressed herein are those of the individual student author and do not necessarily represent the views of either the U.S. Army Command and General Staff College or any other governmental agency. (<u>References to this study should include the foregoing statement.</u>)

A SUGGESTED POLICY FOR INCORPORATING OPERATIONS RESEARCH/SYSTEMS ANALYSIS INTO THE INSTITUTE OF COMBINED ARMS AND SUPPORT'S MANAGEMENT MODEL

An abstract presented to the Faculty of the U.S. Army Command and General Staff College in partial fulfillment of the requirements of the degree

MASTER OF MILITARY ART AND SCIENCE

by

HARRY F. ENNIS, MAJ, USA
B.S., Purdue University, 1958

Fort Leavenworth, Kansas
1968

ABSTRACT APPROVAL PAGE

Name of Candidate HARRY F. ENNIS, MAJ, USA

Title of Thesis A Suggested Policy for Incorporating Operations Research/Systems Analysis into the Institute of Combined Arms and Support's Management Model

Approved by:

Edmund A. Goetsch, LTC, SigC, Research and Thesis Monitor

Robert G. MacLennon, LTC, CE, Member, Graduate Faculty

____________________, Member, Graduate Faculty

Date 27 June 1968

The opinions and conclusions expressed herein are those of the individual student author and do not necessarily represent the views of either the U.S. Army Command and General Staff College or any other governmental agency. (References to this study should include the foregoing statement.)

The U.S. Army must continually strive to maintain its posture with respect to its materiel, organization and doctrine which will permit it to respond to any future threat. The nature of modern warfare requires that the weapons of war be sophisticated, the organizations flexible, and the doctrine effective. In achieving these objectives, many variables must be manipulated to obtain the best possible fighting combination for our national security is at stake. At the same time, this development must be accomplished as economically as possible to preserve our national resources of men, time, and money.

The U.S. Army Combat Developments Command (USACDC) is charged with developing operational, organizational, and doctrinal concepts for the Army of the future. USACDC through its many agencies and institutes undertakes combat development programs which are designed to produce the best possible Army in successive five year periods, 20 years in the future. These Army Combat Development Programs are identified by the year in which they are implemented (e.g., Army 75 or Army 85). The Institute of Combined Arms and Support (ICAS), within USACDC, is responsible for developing the combat doctrine for forces which employ combined arms. In discharging its combat developments responsibilities, ICAS is guided by a management model. To proceed through the development process various critical management/decision check points in this model must be passed. This study is directed to the incorporation of the techniques of Operations Research/Systems Analysis into the aforementioned model to provide the best decisions at the identified check points. It is

essential that modern military managers be cognizant of these valuable aids to decision-making and that these aids be employed to insure the development of the most efficient Army for the future.

The modern analytical methods which are identified by the term Operations Research/Systems Analysis employ scientific and analytical techniques in providing the decision-maker with a more quantitative basis for his decisions. As such, they are not particularly new or revolutionary. However, Operations Research/Systems Analysis differs in one important respect from earlier quantitative analysis efforts in that it's goal is clearly to find the optimum solution to a problem rather than merely suggest a better solution. Quantitative analysis has found application in the military and in industry since before World War II; however, it was during that conflict that the name Operational Research was applied to these techniques when being used by the British in solving problems of RADAR operation. An example of the application of Operations Research/Systems Analysis by the United States during World War II was the interdisciplinary team approach to the development of the world's first atomic bomb. Since World War II, Operations Research/Systems Analysis has been used successfully in the development of such sophisticated weapon systems as the POLARIS and the SENTINEL.

The applications of Operations Research/Systems Analysis have not been limited to the military. Industry has used these modern analytical methods extensively to increase productivity, to improve product quality, and to maximize the distribution function.

Operations Research/Systems Analysis is not proffered as a panacea for curing all of management's ills; indeed, it has some inherent limitations. One must be sure that the problem is one which can be approached by quantitative means. Further, the use of these techniques is expensive in terms of time and money expended and their employment often requires considerable automatic data processing support.

Mathematical and statistical techniques which have application in Operations Research/Systems Analysis range from those which are probabilistic in nature to those which are deterministic. Examples of these techniques are: probability theory, statistical analysis, Monte Carlo techniques, simulation, game theory, and linear and dynamic programming. In the order listed, these techniques are increasingly deterministic; the former being ideally suited for coping with uncertainty; the latter providing rigorous solutions to mathematical models. The methodology used in bringing these techniques to the decision-making process includes the use of: the scientific method, the interdisciplinary team, and mathematical modelling.

How can these techniques and methodology be used to improve the development of the Army of the future? The developmental process must be investigated briefly before one can answer that question. The development process is guided by the Combat Development Objectives Guide (CDOG) and its important objectives and requirements documents; the operational capabilities objective (OCO), the qualitative materiel development objective (QMDO), and the qualitative materiel requirement (QMR). Theoretically, 20 years

should elapse between the identification of the desired operational capability and the introduction of new materiel into the field, during which time the objective is becoming progressively more clearly defined. Concurrent with the final phases of the development, the Tables of Organization and Equipment (TOE) and Field Manuals (FM) are being prepared to provide the organization and doctrine for the Army in the period in question.

To study the incorporation of Operations Research/Systems Analysis techniques into the ICAS Model one must analyze the development process, identify the critical management check points and select the techniques which are applicable. Within the ICAS model, the author identified the following as critical check points.

1. Review and Analysis of Alternative Conceptual Designs.
2. Requests for Input to Doctrine Studies.
3. Analysis and Selection of Best Doctrinal Approach.
4. Comments on Coordination Draft.
5. Analysis and Synthesis of Derivative Studies.

It is suggested that the following techniques might be applied. The order in which they are listed corresponds to the order of the check points listed above.

1. Probability theory and modelling.
2. "Reverse War Gaming."
3. War Gaming.
4. Conventional coordination with operations research assistance in resolving differences.
5. PERT, trade-off analyses, linear and dynamic programming.

In conclusion it should be remembered that Operations Research/ Systems Analysis does not relieve the manager or commander from making decisions, it merely aids these executives in arriving at sound decisions. The Institute of Combined Arms and Support should make full use of these techniques in the pursuance of its combat development responsibilities.

ACKNOWLEDGEMENTS

The author acknowledges that this thesis could not have been completed successfully had it not been for the unselfish contribution of time and effort made by many persons in the Fort Leavenworth community. The author wishes to express his appreciation to all of those persons and in particular to thank his Thesis Monitor, LTC Elmer Goetsch, and LTC John Longbottom, ICAS, for their sage guidance in the selection of a study project. The author is especially indebted to LTC Lee Dickson, ICAS, for his accurate and helpful technical assistance and encouragement during the research and thesis preparation. Further valuable assistance and volumes of research material were provided to the author by LTC Hans Strohm, ICAS, the library staff of the Command and General Staff College, and the Administrative Support Branch of ICAS. Especially noteworthy have been the contributions made by Mrs. Jean Ennis, the author's wife, whose assiduous typing and proofreading made the completed thesis a reality and whose encouragement and forbearance made it possible for the author to complete the research and writing required.

H. F. E.

TABLE OF CONTENTS

LIST OF FIGURES

CHAPTER I

INTRODUCTION

Purpose

The purpose of this thesis is to formulate a suggested policy for incorporating the techniques of Operations Research/Systems Analysis into the Institute of Combined Arms and Support's (ICAS) management model. The ICAS model guides the conduct of the combat development actions taken by the institute during the developmental cycle.

Scope

This thesis is directed toward a study of modern analytical methods, their historical development and their application in industry and in the military. Further, this thesis presents an outline of the current U.S. Army process followed in the development of a new item of materiel. The development of a hypothetical surface-to-surface missile system is the vehicle for exposition of the various stages of materiel development. These stages of development are applicable, in the broader context, to the development of any complex materiel system which may be introduced into the U.S. Army inventory; and indeed to the overall combat development process which provides the doctrine and the organization as well as the materiel for the army of the future.

The study investigates the application of Operations Research/ Systems Analysis techniques as an aid to decision-making during the combat development cycle. From these investigations, a policy is formulated for incorporation of these modern analytical techniques into the Institute of Combined Arms and Support's management model. The policy which is suggested will be applicable to any future time period during peacetime or throughout the spectrum of war to general mobilization.

Depth of the Study

The study does not attempt to present a rigorous mathematical solution to any particular mathematical model. Mathematical symbology is introduced only when necessary to clarify or amplify the verbal presentation. The study does, however, display the most frequently used modern analytical techniques, presenting their strengths and weaknesses and exploring the applicability of these techniques to the decision-making process. The decision-making process in which the developers of army materiel, doctrine and organizations are involved commands a central position in this exploration. The steps that must be taken in the combat development are traced through the development phases of concept formulation, contract definition, development and production, and operations and disposal. The present application of Operations Research/Systems Analysis to the management models in use at the Department of the Army and the Combat Developments Command is investigated and extrapolation is made as to the suitability and advisability of incorporating similar techniques into the Institute of Combined Arms

Support's materiel management model. The policy which is formulated is keyed to the critical decision points in the ICAS management model; however, it is applicable to other combat development models as well.

Organization of Subsequent Material

The remaining material in this thesis is divided into five chapters as follows:

Chapter II addresses the general nature of quantitative analysis which has contributed to the techniques found today in the modern analytical methods of Operations Research/Systems Analysis. It includes a listing of some of the basic definitions which are essential to developing a common understanding of the concepts to be presented throughout the thesis.

Chapter III sets forth some of the modern mathematical and statistical techniques which are the tools of the trade of the operations researcher and systems analyst. Included in this presentation is a discussion of the mechanics of operation, the strengths and weaknesses and appropriate applications of each of the techniques presented. The discussion is punctuated with examples to support the explanation of the operations of the various modern analytical techniques.

Chapter IV outlines the present U.S. Army materiel development cycle using a hypothetical missile system as the vehicle for examining the developmental process. The critical decision points in the development cycle are identified. Also in this chapter, the roles of the diverse agencies which are involved in materiel development are investigated with emphasis being placed on the

present application of Operations Research/Systems Analysis techniques by these agencies to the decision-making process.

In Chapter V, the application of Operations Research/Systems Analysis techniques and methodology to the decision check points within the Institute of Combined Arms and Support's management model is presented. As the application of these modern analytical methods is explored, the techniques are arranged in the order of suggested suitability to the particular phase of the development process. In an appendix, a policy is proffered for the incorporation of these modern analytical techniques into the Institute of Combined Arms and Support's management model.

The sixth, and final, chapter is an epilogue which explores the possibility of a broader application of Operations Research/Systems Analysis techniques to combat development. In this chapter the question is posed of the feasibility of eventually defining the entire developmental process as a single system and optimizing it in the early planning stages so accurately that development can proceed from inception to phase-out without set backs, re-cycling, cancellation or significant slippages. Finally, some general remarks about the future applications of Operations Research/Systems Analysis are made.

CHAPTER II

THE GENERAL NATURE OF OPERATIONS RESEARCH/SYSTEMS ANALYSIS

Introduction

Operations Research/Systems Analysis is a modern extension of classical quantitative analysis and as such is certainly not something new. It can be said that quantitative analysis is as old as the development of the skill of counting on one's fingers, as old as the reckoning of the passage of time from successive risings and settings of the sun or as old as the measuring of the height of an animal by the breadth of one's hand.

Quantitative Analysis - Old and New

The great construction projects of antiquity must have been accompanied by decisions made on the basis of clearly quantitative data. Even the simplest of construction decisions necessarily involve such questions as: How long does it have to be? How wide? How strong?

From antiquity to the present, the decision-making process has undergone successive refinements toward greater quantification. Rather than being a new or revolutionary innovation, the application of modern analytical methods can be viewed as the most recent refinement of the age-old attempt to arrive at better decisions through consideration of more accurate and more quantitative input information.

Quantitative analysis has been developed to its highest degree through its application in the physical sciences. Measurement (which presupposes the ability to quantify data) has been, and continues to be, the essence of scientific experimentation. If the result of an experiment cannot be duplicated under similar conditions, its credibility in the scientific community is severely questioned.

The growth of quantitative analysis has paralleled the growth of the scientific method. Galileo, in formulating his laws of gravitational acceleration, had to be able to measure time and distance.[1] Johann Kepler, in his investigation into the motion of the planets, relied heavily on the astronomical instruments invented by Tycho Brahe and the accurate celestial measurements which they afforded.[2] Sir Isaac Newton would have been unable to verify his general laws of motion, had there been no quantitative standards against which velocity, momentum and acceleration could be measured.

With the advent of the industrial revolution and the introduction of labor saving machinery, quantitative analysis was to have a greatly expanded practical application. What is known today as industrial engineering began to grow as soon as an early production manager analyzed his operation and devised an improved procedure or system for accomplishing his industrial tasks. More will be said in succeeding

---

[1]Philip E. B. Jourdain, The Nature of Mathematics reprinted in The World of Mathematics, by James R. Newman (New York: Simon & Schuster, 1956), I, p. 4.

[2]James R. Newman, The World of Mathematics (New York: Simon & Schuster, 1956), I, p. 218.

paragraphs about these pioneers in scientific management.[3]

How then does Operations Research/Systems Analysis differ from these classical quantitative analysis techniques? It differs in this important respect. Operations Research/Systems Analysis strives to obtain the best solution from a choice of possible solutions, rather than merely to suggest improvements in the present modus operandi.[4] This latter goal characterized earlier quantitative analysis efforts. It is not implied that Operations Research/Systems Analysis will always produce the best solution and is therefore a substitute for considered judgment. It is suggested; however, that these modern analytical techniques increase the manager's repertory of devices which he can bring to bear on the decision-making process.

Definitions

Before proceeding further into the investigation of the modern analytical techniques which will be conveniently, though perhaps somewhat inaccurately, combined into the generic term Operations Research/Systems Analysis; it is necessary that there be an understanding of the definitions of certain terms which will be used frequently as the thesis unfolds. It is interesting to note, though not at all surprising, that in this embryonic discipline there can be found a number of different definitions applied to the same term. Therefore, the definition given will be that which the author believes best describes the term in the context in which it will be used. Where understanding

---

[3]See Industrial Applications, page 18.

[4]See also: Definitions of Operations Research, page 8.

can be enhanced from a comparison of differing definitions, such comparisons will be made.

Operations Research

According to Churchman:

> O. R. [Operations Research] is the application of scientific methods, techniques, and tools to problems involving the operations of a system so as to provide those in control of the system with optimum solutions to problems.[5]

Observe that in this definition, optimization of the solution is a necessary ingredient of the operations research process. In fact, in the discussion which precedes the formulation of this general definition Churchman writes:

> The concern of O. R. with finding an optimum decision, policy, or design is one of its essential characteristics. It does not seek merely to find a better solution to a problem than the one in use; it seeks the best solution.[6]

The Department of the Army definition of operations research does not specifically include the requirement for such optimization. According to the Dictionary of United States Army Terms, operations research is defined as:

> The analytical study of military problems undertaken to provide responsible commanders and staff agencies with a scientific basis for decisions on action to improve military operations. Also known as operation research, operational analysis.[7]

---

[5] C. West Churchman et al., Introduction to Operations Research (New York: John Wiley and Sons, Inc., 1957), p. 18.

[6] Ibid., p. 8.

[7] U.S., Department of the Army, Dictionary of United States Army Terms, AR 320-5 (Washington: U.S. Government Printing Office), p. 283.

Although the Army definition does not require operations research to produce the best solution, it does establish the goal of improving operations through the application of operations research.

Systems Analysis

Although closely related to operations research in many contexts, systems analysis is ascribed a separate definition by most writers. In fact, it is extremely difficult to find an accurate and universally accepted definition of this term. The U.S. Army defines system analysis as:

> An orderly study of management system or an operating system using the techniques of management analysis, operations research, industrial engineering or other methods to evaluate the effectiveness with which missions are accomplished and to recommend improvements.[8]

Systems analysis is further defined in its management context as the ". . . study of methods for obtaining desired results. Emphasizes reporting and control techniques."[9]

Both of the previous definitions emphasize the "backward looking" or controlling quality of this management technique. Lest the reader be misled into believing that all definitions of systems analysis imply that it is merely a control device, the definition suggested by E. S. Quade, who sees systems analysis as a more inclusive management aid, is offered for comparison.

---

[8] Ibid., p. 405.

[9] U.S. Army Command and General Staff College, Readings in Command Management, Modern Analytical Methods, RB 20-5 (Fort Leavenworth, Kansas: 1967), II, Appendix A, Glossary, p. A-5.

> . . . , systems analysis might be defined as inquiry to aid a decisionmaker to choose a course of action by systematically investigating his proper objectives, comparing qualitatively where possible the costs, effectiveness, and risks associated with the alternative policies or strategies for achieving them, and formulating additional alternatives if those examined are found wanting.[10]

Probability

There is a remarkable agreement between mathematicians and statisticians as to the definition of probability. The definition offered here is representative of many similar definitions. "Probability is the likelihood of the occurrence of any particular form of an event."[11]

War Game

A multitude of definitions exists for the term war game. However, the following definition of a war game is the one which will be applied throughout this thesis.

> A simulation, by whatever means, of a military operation involving two or more opposing forces, conducted, using rules, data and procedures designed to depict an actual or assumed real life situation.[12]

Stochastic Process

"A process is stochastic if it includes random variables whose values depend on a parameter such as 'time.'"[13] Models which represent stochastic processes are known as stochastic models.

---

[10] E. S. Quade, Analysis for Military Decisions, R-387-PR (Santa Monica, California: The Rand Corporation, 1964), p. 4.

[11] John R. Stockton, Introduction to Business and Economic Statistics (Cincinnati, Ohio: Southwestern Publishing Co., 1966), p. 195.

[12] U.S. Department of the Army, Dictionary, p. 438.

[13] Churchman et al., Introduction to Operations Research, p. 391.

Deterministic Model

A deterministic model is ". . . a model whose output values are fully determined by the values of the input or independent variable."[14]

Probabilistic Model

A probabilistic model is ". . . a model that makes allowances for randomness in one or more of the factors that determine the outputs of the model."[15]

Historical Applications

The application of science, and particularly quantitative analysis, to the decision-making process has been alluded to earlier in the discussion. In this section some detailed historical examples of such applications will be considered along with the role that Operations Research/Systems Analysis has played in assisting managers to make the best decisions possible. The ensuing material will be divided into a discussion of military and industrial applications of modern analytical methods.

Military Applications

Operations Research/Systems Analysis came into prominence, primarily, as a result of the important role it played during the second World War. It is reasonable then to divide the discussion of the military applications of Operations Research/Systems Analysis

---

[14] U. S. Army Command and General Staff College, Readings in Command Management, p. A-1.

[15] Ibid., p. A-4.

into three periods, namely: Pre-World War II, World War II and Post-World War II periods.

Pre-World War II

National leaders since antiquity have solicited the help of scientists in the pursuance of their military campaigns. One might consider the assistance rendered to Hieron, King of Syracuse, by Archimedes over two thousand years ago in reducing the Roman naval seige of the city as being one of the earliest recorded applications of Operations Research/Systems Analysis (Science) to the conduct of war.[16]

War games which have been defined earlier, have served as important quantitative analysis techniques for studying the effectiveness of battlefield decisions. According to one writer, war gaming had its origin in Iraq five thousand years ago with a chess-like game which was played as much for amusement as for enlightenment.[17] Through the centuries, from that time, war games have played an increasingly important role in the training of military men and in the development of tactics and strategy. During the 17th and 18th Centuries considerable progress was made in refining and embellishing the war games in vogue at the time. Some of the games became

---

[16] Joseph F. McCloskey and Florence N. Trefethen (eds.), Operations Research for Management (Baltimore: The Johns Hopkins Press, 1954), p. 4.

[17] Murray Greyson (ed.), Second War Gaming Symposium Proceedings (Washington: Washington Operations Research Council, 1964), pp. 7-17.

so complex; however, that they lost their appeal to the bulk of the military tacticians. One such game which was introduced near the end of the 18th Century was played on a board consisting of 3600 squares and permitted the maneuver of 1800 brigades on each side together with all of the supporting artillery and logistics. So detailed were the rules of play that they comprised a rule book 60 pages in size. The culmination of such manual war gaming techniques was the German "Kriegspiel" of Von Reisswitz (mid 19th Century) and its extensions in the United States and other countries. History shows the German application of lessons learned from this "Kriegspiel" to railroad employment during the Franco-Prussian War (1870) and to the Von Schlieffen Plan and the Spring Offensive (1918) during World War I.[18]

In addition to the purely stylized war games, which had their greatest application to the tactics of both land and sea warfare, other investigations were being made into the broader use of science and mathematics in the conduct of warfare. Probably the most famous of these investigations were those made by the English mathematician Frederick W. Lanchester who not only offered scientific assistance to his government in the conduct of the naval war but who also foresaw, through his analytical insight, the future application of air power. The American inventor, Thomas A. Edison, made his contribution in this field by performing extensive and detailed studies in the

---

[18]Ibid.

conduct of antisubmarine warfare. Regrettably, the studies of these two men had no effect on the actual conduct of operations during World War I, but they did serve as the foundation for work which was to come with the outbreak of World War II.[19]

World War II

It was during this great struggle, particularly in Great Britain, that modern Operations Research/Systems Analysis had its origin. Science and technology had provided to the British War Office the wonderous device called RADAR, but when installed at defensive sites it did not perform as it had on test sites earlier. The Anti-Aircraft Command Research Group was formed in 1940 by Professor P. M. S. Blackett of the University of Manchester to study the problem on the operational sites. This team, later reknowned as "Blackett's Circus," was composed of three physiologists, two mathematical physicists, one astrophysicist, one Army officer, one surveyor, one general physicist and two mathematicians.[20] This aggregation of scientific and military expertise was to be one of the first of a long line of "mixed teams" which would tackle problems of operations research. The interdisciplinary team will be discussed in greater detail in Chapter III.[21] As the war progressed, operations research techniques continued to be refined. The casualty figures in the actual Luftwaffe attack on Coventry agreed very closely with

---

[19] McCloskey and Trefethen (eds.), Operations Research, p. 4.

[20] Ibid., p. 6.

[21] See page 53.

those which had been predicted previously from ratios developed by Professor S. Zuckerman, distinguished anatomist, using the scientific method.[22]

Another military application of operations research during World War II was the optimization of the effect of bombing raids over Europe by allied forces. Using data collected during bombing raids upon their home island, the British were able to choose the most profitable targets and to estimate the effects in advance. Vulnerability studies were also performed and it was found that the larger bombing raids, in terms of the number of aircraft flown, suffered a smaller percentage of losses than did a smaller formation. Similar conclusions were drawn regarding the optimum size and composition of naval convoys sailing between America and Europe.[23]

One of the most interesting wartime applications of operations research was the celebrated study to optimize the effects of British antisubmarine warfare against German U-Boats. The simple solution proposed by operations researcher Professor E. J. Williams was that the settings of the firing device of the antisubmarine bomb be changed so that the bomb would explode, not at the 100 foot depth, but closer to the surface where the submarines were located. This change resulted in an increased effectiveness of from 400 to 700 percent (depending on the source of the reports). So successful was

---

[22] J. G. Crowther and R. Whittington, Science At War, (New York: Philosophical Library, Inc., 1958), pp. 98-99.

[23] Ibid., pp. 110-21.

this improvement " . . . that German crews were reporting that new and more powerful mines were being used against them."[24]

The United States was not far behind Great Britain in applying operations research techniques to her war effort. In the sea war against Japan, studies in both offensive (mining of Japanese shipping routes) and defensive (avoidance of kamikaze hits) naval tactics were pursued with great success. The final and possibly the most significant operations research project undertaken by the United States during World War II was the Manhattan Project. This project brought the talents of the scientist, engineer and military man together for the production of the world's first atomic bomb.

Post-World War II

Since the end of World War II, Operations Research/Systems Analysis has continued to flourish. This continued growth supports the premise that Operations Research/Systems Analysis is a valid and worthwhile management technique to be employed not only while under the pressure of global conflict; but to be applied with equally successful results to the routine, though important, peacetime improvement of a nation's military posture. What have been some of the post-World War II military applications of Operations Research/Analysis? No discussion of the recent applications of modern analytical methods could proceed without the recognition of the tremendous contribution made to this discipline by the advent and

---

[24]McCloskey and Trefethen (eds.), Operations Research, p. 9.

increasing use of electronic computers. The speed with which these machines can handle complex and repetitive mathematical and simple logic operations has enabled the operations researcher to participate in war gaming to an extent heretofore impossible using manual computation methods. The multitude of combinations and interrelations of the parameters of the size of force, weapons superiority, relative mobility, and the like, can now be manipulated electronically and in seconds, provide output data which can serve as a guide to military decision-makers.

One of the most successful applications of modern management techniques has been the systems approach to the development of the Fleet Ballistic Missile Weapons System; better known by its common name, the Polaris Submarine. In the development of this system, one of the most complex and sophisticated of all weapons systems, a single program management organization was established. This organization, the Navy Special Projects Office, was a Manhattan Project-type organization with full responsibility and authority for the development of the weapon system in the shortest time possible. The approach used divided the total system into subsystems and then through the application of such modern management techniques as PERT (Program Evaluation and Review Technique) integrated each of the subsystems into the total operational unit.[25] The PERT system was developed jointly by the Navy; Booz, Allen and Hamilton;

---

[25] Richard A. Johnson, et al., The Theory and Management of Systems (New York: McGraw-Hill Book Co., Inc., 1963), p. 133.

and the Lockheed Aircraft Corporation especially to cope with the Polaris development program.[26] The success of this integrated systems approach is well known with the Fleet Ballistic Missile Weapon System becoming operational more than two years ahead of schedule.

A further improvement in the application of PERT is the introduction of what is known as PERT/COST. In employing this technique, the costs associated with each of the various decision variables are taken into account and cost effectiveness as well as performance effectiveness is determined. This feature is particularly important in light of the extremely burdensome costs associated with the development of sophisticated weapons systems. The most efficient use can be made of the limited resources of time, material, manpower and money if this technique of PERT/COST is conscientiously applied.

Industrial Applications

Operations Research/Systems Analysis, as we know it today, was born of necessity within the military framework of the second world war. It has expanded its scope rapidly; however, to encompass industrial applications and has made significant contributions to industry as it had done earlier in its military applications. This is not to say that there was no application of science and the scientific method to industry before World War II; rather that, only after the war were the techniques of Operations Research/Systems Analysis incorporated into the quantitative analysis methods already being

---

[26] Ibid., p. 247.

employed. A brief sketch tracing the development of scientific management in its attempt to make the industrial sector of our economy more efficient will be presented in the following paragraphs.

The mechanization which characterized the industrial revolution had been burgeoning for over 100 years before any significant contribution in the scientific management of business and industry was seen. In the last 20 years of the last century various pioneers in management science began plying their trade. These men formulated the doctrine that the scientific method was applicable to industrial applications, and that, "wherever possible, business decisions should be based on facts rather than on someone's intuition or emotion."[27]

One of the most famous of these pioneers was Frederick W. Taylor whose time and motion studies serve as the cornerstone of modern management science. Taylor's work was not particularly revolutionary, indeed by his own admission:

> It will doubtless be claimed that in all that has been said no new fact has been brought to light that was not known to someone in the past. Very likely this is true. Scientific management does not necessarily involve any great invention, nor the discovery of new or startling facts . . . .[28]

The contribution he made which has proved to be of inestimable value was that he addressed the problem of increasing production by application of the scientific method (i. e., careful observation, analysis of findings, confirmation by experiment and refinement of test results).

---

[27]McCloskey and Trefethen (eds.), Operations Research, p. 81.

[28]Frederick Winslow Taylor, quoted in McCloskey and Trefethen (eds.), Operations Research, p. 82.

In the early years of this century industry operated under the pressure of the demand for increased productivity. Therefore, managers responded with efforts which we now view as rudimentary industrial engineering. This activity was characterized by a continued application of time and motion studies and by increased emphasis on the quantitative factors of cost, man-hours of labor, units of output, and the like. Production-line techniques which were introduced on a large scale during this period were indicative of the efforts made to increase the productive capacity of industry.

Shortly thereafter, however, the emphasis began to shift from quantity considerations to considerations of quality. Attention was given to the waste and loss of material, time and money which resulted from the production of "factory rejects." Here too, refinement of the control function of management was provided by management service. Management's interest in quality resulted in the introduction of statistical quality control shortly after World War I. This technique has since been accepted as an effective device for making decisions with respect to the quality of manufactured products.[29] It cannot be said that this aspect has ever been subsequently deemphasized. Consider, for example, the recent development by the Martin Company of the "zero defects" program which in its extreme application would provide the ultimate in quality control. This program promises such success in the area of quality control that it has been enthusiastically adopted by many industrial and government organiza-

[29] Stockton, Introduction to Business and Economic Statistics, p. 285.

tions, not the least of which being the Department of Defense.

Continued use of the operations research interdisciplinary teams can be seen in the solution of industrial quality control problems. Professor Loring G. Mitten, Professor of Industrial Engineering, Ohio State University, provides an example of such a team which was assembled at the request of a large manufacturing company to study its visual inspection and quality control methods. The team he described was composed of a research optometrist, a psychologist, a college professor, an industrial engineer and a statistician.[30]

After the quantity and quality of production were brought within acceptable limits, industry turned once again to science for assistance in the distribution function. Thus the relatively new disciplines of marketing research, consumer surveying, rhocrematics[31] and others have sprung up to aid in the profitable distribution of the myriad of products which industry is now capable of producing. Management is placing increased reliance on the management consultant who is expected to bring the scientific method to bear on the problems of industry. One of the earliest examples of the application of modern operations research to the management consultation field is provided by Horace C. Levison whose work in the 1920's for L. Bamberger and Co., improved marketing techniques by scientific

---

[30]Churchman, et al., Introduction to Operations Research, p. 58.

[31]Johnson, et al., The Theory and Management of Systems, p. 16, write, "The term rhocrematics has been coined to connote the flow process from raw-material source to final consumer."

study of such parameters as, hours of operation, newspaper advertising customer buying habits and effects of neighborhood environment on sales.[32]

What has Operations Research/Systems Analysis done to change the tenor of these progressively sophisticated management techniques? Operations Research/Systems Analysis has broadened the perspective of the traditional "efficiency expert" considerably. The modern analysts are literally involved in research of the entire operation, be it production, sales, advertising or even military in nature. Each management science technique previously discussed concerned itself with a segment of the complete operation and although many of these techniques streamlined the segments to which they were directed they did not have as their objective the optimization of the entire operational system. Operations Research/Systems Analysis necessarily addresses itself to optimization of the overall operation and views its goal in terms of total system effectiveness. Thus, its focus of attention is on ". . . relating communication systems, organization structure, questions of growth, and questions of uncertainty."[33] The inclusion of social scientists, and others with unlikely talents, on the mixed team demonstrates this shift of attention to a consideration of more and complex variables.

---

[32]McCloskey and Trefethen, Operations Research, p. 29.

[33]Johnson et al., The Theory and Management of Systems, p. 12.

Capabilities

The discussion of the general nature of Operations Research/ Systems Analysis thus far has sketched the application of quantitative analysis through its various classical and modern applications to its solution of military and industrial problems. In this section the capability of Operations Research/Systems Analysis techniques to expand the manager's capacity for performing his traditional functions of organizing, planning, coordinating, directing and controlling will be explored.

Organizing

Traditionally, if a manager wished to organize his work force there were certain well established rules for doing so which had been formulated by successful managers before him and which outlined the organizational structure that worked well for them. In fact, most managers either "grew up" in the organization or had it handed to them "ready-made" and little thought was given to making extensive changes. This phenomenon represents a natural tendency to leave well enough alone. Although adherence to this policy might well produce successful results, it is more likely that such a static organization would be clumsy, at best, and perhaps incapable of coping with the rapidly changing industrial world. Operations Research/Systems Analysis encourages the manager to view the structure which relates the people and the facilities at his disposal in the broader context of what the entire socio-industrial system hopes to achieve. In this context relationships may appear which were obscured by the lines and blocks

of the traditional organizational chart. The interdisciplinary research which is conducted will provide from the social sciences such clues to greater efficiency as motivational incentives, informal relationships and conflicts of interest within the proposed or existing organization. According to Johnson:

> The manager should understand the business, not as a number of isolated parts, but as subsystems; he must have knowledge of the relationships between the parts and be aware of their potential interaction.[34]

Operations Research/Systems Analysis can provide the manager with the knowledge needed to achieve that understanding.

Planning

Planning by its very nature must be an integrated function if it is to accurately guide the organization from the present to the attainment of future goals. A common stumbling block to effective planning is that it is done piecemeal by either a staff agency which is not intimately familiar with the functions at the operating level or by individual operational elements within the organization without regard to the broad objectives of the organization as a whole. Systems analysis provides the required integration since it identifies and publicizes the over-all objectives and goals of the organization to which all elements can direct their effort.

Coordinating

Coordinating within a business, or any other social organization, is the achieving of unanimity of thought and action among the

---

[34] Ibid., p. 55.

separate elements of which it is composed. Problems in coordination are closely related to problems in communication. If the respective departments of a business have different understandings of the policies and procedures of the top management, no amount of cooperative effort between these departments will result in effective coordination. Operations Research/Systems Analysis, in applying the integrated systems approach to the activities of the business, should be able to provide the basis for the common understanding through the development of common terminology, policy statements, procedures and reporting formats. Once the common base is thus established, the manager will be able to more effectively coordinate the activities of the individuals and departments under his control.

Directing

Directing is, and will always be, a function of management which is very closely related to the personality of the manager. As such it may seem that the quantitative analysis techniques of Operations Research/Systems Analysis will have little application to this management function. However, it must be remembered that it is the response of the individual to the direction that is the important consideration in assessing the effectiveness of this management function. Thus, if the subordinates in an organization know that their actions are being guided by decisions which are based on scientific and analytical foundations rather than on intuition and guesswork it is reasonable to assume that they will be more inclined to respond favorably to the direction. The fact that Operations Research/Systems Analysis may aid the manager in publishing directives which

are technically correct does not; however, relieve him of the responsibility of delivering the directive " . . . in the proper tone of voice or choice of words, by the right individual, and with the proper timing."[35] to assure maximum compliance.

Controlling

Of all the management functions, controlling is perhaps the one which can benefit most from the application of Operations Research/ Systems Analysis techniques. The controlling function involves determining when actual performance is deviating from the desired performance and then taking corrective action quickly enough to restore order and keep the system on course to its intended objective. Operations Research/Systems Analysis can serve this function in two important ways. First, if the system has been properly designed, deviations from the norm will be sensed immediately, as they occur, and will be reported to management in "real time"[36] through electronic means for corrective action. Second, in the application of corrective action, reallocation of resources may be necessary involving trade-off decisions. Operations Research/Systems Analysis is uniquely equipped to review proposed trade-offs and to recommend the one which will yield the most satisfactory results.

---

[35]U. S. Army Command and General Staff College, Readings in Command Management - General, RB 20-5 (Fort Leavenworth, Kansas: 1967), I, p. 1.11.

[36]According to Stockton, Introduction to Business and Economic Statistics, p. 51. " . . . promptly enough to be of use in controlling the process while it is still occurring."

The time has passed when a business or military manager could hope to effectively control his entire operation alone. He must be assisted in juggling many variables and integrating them into an effective whole. It is to this end that Operations Research/Systems Analysis is directed.

Limitations

It would be grossly unfair, even in a discussion of the general nature of Operations Research/Systems Analysis, to present only the accomplishments and optimistic prospects of continued successes of these modern analytical methods without calling attention to some limitations to their application. In this section, shortcomings of these methods that should be recognized and pitfalls that should be avoided will be presented.

Shortcomings

One of the shortcomings of Operations Research/Systems Analysis is inherent because of the scientific nature of the techniques employed. Since the methods are scientific and objective there is no guarantee of success. It is hoped that the application of the scientific method will give greater insight into the operation being studied and it usually does. However, these insights sometimes fail to offer solutions which can be applied within the practical constraints of time and resources limitations.

Another important shortcoming is related to the necessity to reduce the variables to measurable quantities which can be manipulated in mathematical or other symbolic models. In certain problems there exist pertinent variables which cannot be quantified. This

shortcoming is exposed by persons who argue that Operations Research/Systems Analysis is not applicable to military situations where the outcome is so strongly influenced by such intangible factors as morale, esprit de corps and leadership. Indeed, in this connection Dr. Alain C. Einthoven has said:

> Of course, there are many things that simply cannot be calculated; for example, the reliability of an ally, or the psychological or political consequences of a military operation. And these non-quantitative factors may dominate the problem. . . .[37]

Another problem arises when the results of the scientific analysis are misinterpreted. Many managers fall, unwisely, into accepting blindly all recommendations produced by Operations Research/Systems Analysis techniques. Military leaders are not exempted from this failing. Fortunately, few, if any, of the practitioners of Operations Research/Systems Analysis hold it forth as a panacea for solving military decision-making problems. In fact, there is agreement among these practitioners ". . . that the solving of broad military problems requires intuition and judgment as well as analysis, and that models and the results of computations cannot, in themselves, make decisions."[38]

Finally, the application of Operations Researcy/Systems Analysis techniques is expensive in terms of both time and money. To provide some idea of the costs and time involved in accomplishing operations research projects, reference is made to a current printing

---

[37]Alain C. Einthoven quoted in Colonel James B. Hayes' "Systems Analysis," Army (February 1964).

[38]E. S. Quade, Analysis for Military Decisions, p. 12.

of *A Manager's Guide to Operations Research* by Ackoff and Rivett:

> In general, industrial OR projects seem to take between 3 and 12 months to complete. A new OR team of two or three people should, after its initial birth pangs, be able to tackle between one and two projects a year. The use of an outside consulting group working with a company group will reduce this time quite significantly, perhaps as much as 50 percent. An outside commercial consulting group will probably charge up to about $250 . . . per man day for its services, ...[39]

If; however, the services of a full time operations researcher are required:

> An OR man with sufficient experience to direct an OR activity cannot be obtained for less than $15,000 per year, but salaries between $18,000 and $25,000 are more common. Some top people in the field may cost even more.[40]

It should be borne in mind that the cost figures cited are only approximate and that actual costs will depend on the experience and talents of the men involved.

Pitfalls

The pitfalls that will be discussed in this section are not necessarily unique to the discipline of Operations Research/Systems Analysis, indeed some of them can be found in almost all scientific endeavors. The author will select those for discussion which he feels are most likely to obstruct the way of the military decision-maker.

As is true in most activities, one of the most troublesome pitfalls in Operations Research/Systems Analysis is getting started

---

[39]Russell L. Ackoff and Patrick Rivett, *A Manager's Guide to Operations Research* (New York: John Wiley and Sons, Inc., 1965), p. 85

[40]*Ibid.*, p. 74.

properly. It is very important that the type of problem chosen is indeed amenable to the application of these modern analytical techniques and that there is a clear understanding of what the problem really is. As J. R. Goldstein points out in his Scientific Aids to Decision Making: "After all, if we are unclear about what it is we are really seeking, no advances in analytic techniques are going to help us very much."[41]

The pitfall of "modelism" is all too common among inexperienced analysts. This pitfall occurs when the analyst becomes more interested in the model than he is in the real world. Remember that models represent the real world yet cannot include everything. Therefore, what is left out is every bit as important as what is included. It would be a serious mistake; for example, to ignore some pertinent data because its inclusion into the model would make the model cumbersome and less easy to deal with mathematically.[42] Objectivity and honesty can go a long way toward overcoming this pitfall.

A pitfall to which military decision-makers are particularly susceptible is that of adhering to the "party-line" of superiors or the organization instead of presenting the undiluted findings of an analysis. The primary reluctance to presenting a candid conclusion is that the solution derived from analysis may not be the one the boss is looking for. Courage of his convictions and faith in his analysis

---

[41] J. R. Goldstein, Scientific Aids to Decision Making, P-1042 (Santa Monica, Calif.: The Rand Corporation, 1957), p. 7.

[42] Herman Kahn and Irwin Mann, Ten Common Pitfalls, RM-1937 (Santa Monica, Calif.: The Rand Corporation, 1957), p. 1.

will prevent the operations researcher from becoming a victim of this pitfall.[43]

Finally, the pitfall of over-ambition deserves attention because it is the one that snares the conscientious, though usually inexperienced, systems analyst. This pitfall consists of merely trying to do too big a job. Before a study is undertaken, its limits must be clearly defined. "If it can't be limited, in a sensible way, it probably shouldn't be done."[44]

Summary

In this chapter, the general nature of Operations Research/ Systems Analysis was discussed. It was pointed out that the modern analytical methods associated with Operations Research/Systems Analysis are an extension of quantitative analysis which had developed through the ages in the physical sciences, engineering and industry. Definitions of some of the specialized terms to be encountered throughout this thesis were presented. The historical applications of quantitative analysis in the military and in industry were outlined and the contributions of such pioneers as Lanchester, Edison and Taylor were discussed. Operations Research/Systems Analysis was related to the functions of management in an effort to show how these modern management techniques could expand the capability of the manager to perform his management functions. The essential

---

[43] E. S. Quade (ed.), Analysis for Military Decisions, p. 306.

[44] Kahn and Mann, Ten Common Pitfalls, p. 34.

characteristic of Operations Research/Systems Analysis, viz., its quest for the best solution rather than merely the striving for improvement, was emphasized. Finally, some limitations on the use of Operations Research/Systems Analysis techniques were presented by way of a discussion of shortcomings and common pitfalls that the prospective user should guard against.

In Chapter III, the mathematical and statistical techniques in general use in the field of Operations Research/Systems Analysis will be presented.

CHAPTER III

MATHEMATICAL AND STATISTICAL TECHNIQUES

Introduction

In the preceding chapter, the general nature of Operations Research/Systems Analysis was explored; historical examples of quantitative analysis were given; and some of the capabilities, shortcomings and pitfalls inherent in the application of Operations Research/Systems Analysis techniques were discussed. In this chapter, the most common mathematical and statistical techniques which find application in these modern analytical methods will be presented with an exposition of their *modus operandi*, their predominant strengths and weaknesses and the types of problems to which these techniques may be appropriately applied. Examples of each technique to be investigated will be provided to support the explanation of the operations involved in each of the particular techniques. Following the presentation of the techniques, the methodology which is used to bring these techniques to bear on management problems will be discussed.

Techniques

As was noted in the previous chapter, the tools of the modern Operations Research/Systems Analysis practitioner had their origins in the scientific method which had been used so successfully in the advancement of the physical sciences. Quantitative analysis; with its

improved mathematical, and experimental techniques, contributed greatly to the development of the management sciences. Thus, a listing of the techniques drawn from such an extensive background could indeed be quite lengthy. The ensuing discussion is not intended to be exhaustive; rather it is intended to present a representative portion of the myriad of techniques which find application in modern management.

The following techniques will be investigated in turn.

1. Probability Theory.
2. Statistical Analysis.
3. Monte Carlo Techniques.
4. Simulation.
5. Game Theory.
6. Linear and Dynamic Programming.

Probability Theory

Operations research concerns itself with assisting the manager in making the best decision possible regarding a course of action which will affect his operation in the future. Uncertainty is an unavoidable corollary to any investigation into future occurrences. Probability theory furnishes a tool for coping with uncertainty. At the outset it should be understood that the application of probability theory does not reduce uncertainty nor does it give the user a clairvoyance which permits him to foresee future events. What probability does provide; however, is the ability to measure the uncertainty and to do so in quantitative terms which can then be manipulated as mathematical entities.

Stated simply, the outcome of any event can be described by the extremes of probability. Either the outcome is a certainty or it is impossible.[1] A trivial example from classical physics is offered in explanation. In the earth's gravitational field, a free object released from a height above the ground will fall. The probability of it falling is a certainty (expressed as 1), and the probability of it not falling is an impossibility (expressed as 0).

Unfortunately (or perhaps fortunately) the decisions which must be made by managers do not involve such trivial outcomes. Indeed, the possible outcomes are far more interesting and consequently more vexing when they involve the entire range of probabilities that may occur between 0 and 1. A simple example of a probability that falls between these two extremes is the probability of obtaining a "head" on a single toss of an unbiased coin. The probability of this outcome is expressed as:

$$P(h) = 1/2$$

Where P(h) is the probability of a "head" showing and the fraction, 1/2, expresses that the "head" has one chance in two (the two possible outcomes being: one "head" or one "tail") of showing. This probability can be expressed in another way as follows: In an infinite number of tosses, "heads" will come up as many times as will "tails." This is an important concept when dealing with the practical applications of probability theory and will be discussed in greater detail below when

---

[1]U.S. Army Management Engineering Training Agency, Operations Research Appreciation (Rock Island, Illinois: December 1966), p. II-1.

the weaknesses of this technique are addressed. Through these simple examples one can see how uncertainty can be quantified through the use of probability theory.

The strengths of the application of probability theory lie in the fact that it can provide practical conclusions as to the interaction of many variables whose cause and effect relationships are so numerous or complex as to defy determination by more exact means (e.g. experimentation, chemical analysis, etc.). This point is made very clear by Warren Weaver when he writes:

> For in a vast range of cases in which it is entirely impossible for science to answer the question "Is this statement true?" probability theory does furnish the basis for judgement as to how likely it is that the statement is true.[2]

If anything could be cited as a weakness in probability theory it is that the theory is often misunderstood and its results incorrectly applied. As was pointed out earlier, probability does not provide a crystal ball which eliminates uncertainty. Another apparent weakness is that probabilities can never be known exactly. To know the probabilities exactly, the number of observations upon which their determination is based would have to reach to infinity which, of course, is a practical impossibility. This apparent weakness is not significant when one realizes that there are various procedures which can be used to estimate probabilities as accurately as is desired, or required, in any given situation. These procedures will be discussed in detail in the section of this chapter which deals with statistical analysis.

---

[2]Warren Weaver, "Probability," Scientific American, Oct 1950 p. 46.

There are two general categories of problems to which probability theory is applicable. The first of these categories contains those problems which, although amenable to rigorous scientific solution, are not tractable because the complexity or obscurity of the factors involved make their outcome unpredictable from a practical point of view. In treating these problems, probability is used as a convenience. The second general category of problems contains those which are ". . . essentially and inescapably probabilistic." such as quantum theory which attempts to provide, in part, the basic theory of the physical universe.[3] In treating this category of problems the use of probability theory is a necessity.

It will be shown in the following section that probability theory also serves as the foundation for statistical analysis and inference.

Statistical Analysis

It is a short step from the discussion of basic probability to a discussion of statistical analysis. Statistics uses basic probability theory in providing the analyst with a means for studying large volumes of data in the most economic fashion. For example, it may be desirable to know the average physical dimensions of all draft-age United States' male citizens as part of the input data for the design of the crew compartment of a future combat vehicle. How would one obtain such an average? Of course, the most accurate way is to measure all of the United States' male citizens which fall into the draft-age bracket (the total of such male citizens is called the

---

[3]Ibid., pp. 44-46.

population in statistical terminology), then take a simple arithmetic average of their measurements to determine the input data required. Even if the practical hardships of locating and measuring each element in the test population could be overcome, the cost involved and the time required to obtain such an average would surely be prohibitive. Herein, statistics finds its most valuable application in providing the analyst a means for studying only a small portion of the entire population (the sample) and determining, to whatever degree of accuracy required, information which is characteristic of the entire population.[4] In discussing the statistical sampling technique Optner writes:

> This technique prescribes the sample size to be able to infer what the total population is like. Obviously, the larger the sample, the better; to reduce the error of an estimate about 30 per cent requires doubling the sample size. Eventually there is trade-off between cost of data collection and required accuracy for the intended purpose.[5]

He goes on to write, regarding the inferences which can be drawn from such sampling techniques, "Statistical inference can tell whether or not an apparent relationship is truly significant, or the result of chance."[6]

This capacity of statistical inference for being able to determine the significance of its own findings is important enough to deserve

---

[4]The terms population and sample as used here come from definitions provided by John R. Stockton, *Introduction to Business and Economic Statistics*, (Cincinnati, Ohio: Southwestern Pub. Co., 1966), p. 8.

[5]Stanford L. Optner, *Systems Analysis for Business Management* (Englewood Cliffs, N.J.: Prentice Hall, Inc., 1960), p. 159.

[6]*Ibid*.

more attention. An analyst would have very little confidence in the statistical inference findings if he had to concern himself with such questions as "Perhaps the sample I chose was not large enough?" or "Perhaps the sample I chose contained, by chance, all the little people in the total population?" However, statistics can be used to test these questions and to establish whatever confidence level is desired. It is important to realize this fact at the outset of any statistical analysis because it is necessary for the statistician to know the desired confidence level before he begins his analysis. Once the confidence level is established he can proceed. Through application of the techniques of correlation and regression analysis it can be determined how well (or how poorly) the sample data corresponds to the data that would be obtained from a study of the entire population.[7]

Statistical analysis finds its greatest strength in its ability to sample large populations, drawing inferences regarding the total population from the sample and in so doing saving considerably the valuable resources of time and money. High speed electronic computers have greatly expanded the ability of the statistician to provide accurate and timely data to management which serve as the quantitative basis for many management decisions.

Statistical analysis, much like probability theory, possesses an inherent weakness if its findings are not understood or are misused by managers. Since statistical inference is based on probability,

---

[7]The correspondence referred to here is variously known as "goodness of fit" or "curve-fitting" in representative statistics textbooks.

exact prediction of the future is not possible. The more accurate you wish the results to be; the greater must be the expenditure in time and money. The user is cautioned by Levison in a discussion of statistical inference: "When statistics answers a question for you, always look for a tag of some sort carrying a reference to chance. Its absence is a clear danger signal."[8]

The applications of statistics to business and industry are well known. Perhaps the best known application is that of the statistical sampling techniques used in industrial quality control. There are many military applications of statistics also. Artillery firing tables are compiled using statistical analysis of the impact points of artillery rounds fired under controlled conditions. Human engineering conducted to insure compatibility of the man-machine combination on the battlefield, relies heavily on sampling techniques as was discussed earlier.

A refinement of these statistical sampling methods is the now famous Monte Carlo Technique which will be discussed briefly below.

Monte Carlo Techniques

One may wonder how such a picturesque name has come to be applied to one of the mathematical/statistical techniques found in the realm of modern analytical methods. The application of the name "Monte Carlo" to a mathematical technique which had been known for years is attributed to the eminent mathematician John Von Neumann who gave the technique this code name during his

---

[8] Abe Shuchman (comp.), Scientific Decision Making in Business (New York: Holt, Rinehart and Winston, Inc., 1963), p. 276.

secret work at Los Alamos during World War II.[9]

What is the Monte Carlo technique? It is interesting to note that some authors treat Monte Carlo as an extension of statistical sampling,[10] others treat it as a type of simulation[11] while still others view it not as simulation, but as a technique which points up the need for development of simulation techniques[12] (simulation will be discussed separately below).

For simplicity, Monte Carlo will be herein discussed in the first context; that of an extension of statistical sampling. As was mentioned earlier, a wide range of problems confronting the systems analyst can be solved through the use of statistical analysis and sampling. Monte Carlo techniques are especially useful in speeding up and simplifying the sampling process and provide sufficiently accurate results to be used in most decision-making problems. Monte Carlo is an appropriate cognomen since it employs chance in the selection of the sample to be investigated. A table of random numbers is generally the vehicle used for selection of the random sample. Thus, the close similarity between statistical sampling and Monte Carlo sampling becomes apparent. E. S. Quade distinguishes

---

[9] Ibid., p. 396.

[10] E. S. Quade, Analysis for Military Decisions, R-387-PR (Santa Monica, Calif.: The Rand Corporation, 1964), p. 240.

[11] U. S. Army Management Engineering Training Agency, Operations Research Appreciation, p. III-1.

[12] Richard A. Johnson, et al, The Theory and Management of Systems (New York: McGraw-Hill Book Co., Inc., 1963), p. 227.

between the two:

> The origins of Monte Carlo lie in the random sampling investigations of statisticians. The distinction between the two is that the Monte Carlo approach seeks answers to mathematical problems and is dealing with an abstract, rather than with a real, population.[13]

It should be noted that there are populations of data which contain certain random characteristics which preclude their being treated by conventional statistical techniques. In such cases Monte Carlo becomes a necessity if the population is to be analyzed at all. The classical example of such an application of Monte Carlo to a complex population was the investigation into the behavior of neutrons during the atomic weapons development of World War II. Both deterministic and random factors influenced the passage of neutrons through a shield of a given design. Monte Carlo was used to construct a mathematical analogue (model) and the neutron paths were determined using random numbers. Because of the influence of the random factors on the behavior of the neutrons, it is unlikely that the analysis of a large number of experimental observations would have been able to produce any better answer to the basic behavior problem than did the Monte Carlo sampling process.[14]

The strengths and weaknesses of Monte Carlo techniques are much the same as those discussed under statistical analysis with the additional advantages of:

1. Permitting the selection and manipulation of a smaller size sample, thus facilitating computation.

---

[13] Quade, Analysis for Military Decisions, p. 240.

[14] Ibid., p. 241.

2. Permitting the analyst to cope with complex populations; the analyzing of which would be impossible, expensive or extremely time consuming without the application of Monte Carlo techniques.

Monte Carlo techniques have extensive applications in the field of Operations Research/Systems Analysis as will be seen in succeeding sections of this chapter. In particular, Monte Carlo techniques will find application to problems involving waiting-lines, transportation, production, inventory and distribution all of which are usually affected by complicated random factors.[15]

Since random numbers are used in this technique to construct a sample representing real world occurrences, one can see some justification for viewing Monte Carlo as a type of simulation. Simulation as a separate operations research technique will be discussed next.

Simulation

Simulation as a quantitative management technique is considered by some to be ". . . one of the great advances in the science of business management developed in the past decade."[16] Despite its common usage as an operations research technique, simulation is still the subject of some confusion in terminology. To clarify any misunderstandings, this discussion will begin with a representative

---

[15] Johnson, et al., The Theory and Management of Systems, p. 227.

[16] Shuchman (ed.), Scientific Decision Making, p. 510.

definition of simulation.

> By simulation is meant the technique of setting up a stochastic model of a real situation, and then performing sampling experiments upon the model. The feature which distinguishes a simulation from a mere sampling experiment in the classical sense is that of the stochastic model.[17]

See page 10 for a definition of stochastic model.

Since both simulation and Monte Carlo techniques involve random variables, how then are they different? The primary difference can be viewed as being one of scope. The Monte Carlo techniques provide a random sample (sometimes quite small); whereas simulation constructs an abstract model of the entire system to be analyzed. The advantage and strength of the simulation technique should be quite clear. With the entire system modeled; the variables, and their relationships with one another, may be changed with pencil and paper or with the help of a computer and costly experimentation with the actual operation can be avoided. The methodology of model construction will be discussed in a succeeding section of this chapter.

Simulation of a system of any significant magnitude cannot be attempted without a computer. As is true with Monte Carlo sampling, detailed data are being generated through simulation; however, in much greater volumes. This computer dependence can be viewed as a weakness of the technique.

Simulation techniques are ideally suited for application to most large-scale Operations Research/Systems Analysis problems.

---

[17] John Harling, "Simulation Techniques in Operations Research: a Review," Operations Research, May-June, 1958, p. 307.

Indeed, the construction of the stochastic model, which is characteristic of simulation, parallels one of the basic aims of operations research as expressed by Churchman: "O. R. [Operations Research] tries to find the best decisions relative to as large a portion of the total organization as possible."[18] Thus, simulation techniques realize their greatest potential value when applied to the analysis of large and fairly complex systems problems for which specific solutions are being sought. Simulation may also be used for solution of small-scale operations research problems but, manifestly, not as efficiently.

One of the most interesting and potentially useful simulations in use in the operations research field today is gaming. Game theory, and gaming in particular, will be discussed in the following section.

Game Theory

When one begins to discuss game theory and gaming, one runs the risk of getting into a semantics battle. Some authors entirely divorce the two,[19] while others display gaming as an application of game theory to a particular problem at hand (e.g. business gaming or war gaming).[20] In the remainder of this section, the second position ennumerated above will be adhered to.

---

[18] C. West Churchman et al., Introduction to Operations Research (New York: John Wiley and Sons, Inc., 1957), p. 6.

[19] Johnson, et al., The Theory and Management of Systems, pp. 226-230.

[20] Joseph F. McCloskey and Florence N. Trefethen (eds.), Operations Research for Management (Baltimore: The Johns Hopkins Press, 1954), pp. 109-111.

A broad, but workable, definition of game theory is provided by Martin Shubik:

> Game theory is a method for the study of decision-making in situations of conflict. It deals with problems in which the individual decision maker is not in complete control of the factors influencing the outcome.[21]

The definition for war gaming given in Chapter II is seen to be compatible with this general definition of game theory. A detailed discussion of war gaming will be presented later in this section.

Although some of the differences of opinion alluded to previously do exist in this area of game theory, there is; nonetheless, general agreement as to which characteristics must exist in any game. These characteristics may be summarized as follows:

1. There must be a finite number of players or decision-makers.

2. The game must have definite rules.

3. The game must have a payoff or outcome.

4. Values must be assigned to the outcomes so that a winner can be determined.

5. The variables which each player controls must be known so that through their manipulation, alternate strategies are available to each player.

The object of the game is for each player to select the strategy which will yield him the most valuable payoff if he wins and result in

---

[21]Shuchman (comp.), Scientific Decision Making, p. 332.

the least loss if he loses. The interesting feature, and the one which adds realism to the game, is that the outcome is not determined by the action of one player alone. The interaction of two or more player's variables determines the outcome.

There are generally considered to be two basic categories of games, viz., the zero-sum game and the non-zero-sum game. In the zero-sum game the value lost by one player is exactly equal to the value won by the other player. Thus, by definition, zero-sum games involve only two players (of course, each of the players may be a corporate entity consisting of hundreds of individual persons acting in concert). In a non-zero-sum game some third party receives a portion of the payoff.[22] Simple non-mathematical examples of each of these types of games will be given to clarify the discussion.

Consider as a zero-sum game the matching of coins to determine which of two contestants will buy coffee for both contestants in the coffee shop. The rules of play are simple: the coins are tossed but not exposed to view, one player announces that if the coin which he is holding matches that of his opponent that he wins and his opponent loses, the coins are displayed and the outcome is decided. To win in this case means that the opponent player buys the coffee or the winner gains one cup of coffee and the loser forfeits the value of one cup of coffee.

By inserting a third person into the above contest, an example of a non-zero-sum game is provided. In a three-way toss for coffee,

---

[22]U.S. Army Management Engineering Training Agency, Operations Research Appreciation, p. VII-2.

the loser always loses more than he had the opportunity of winning because the third party to this contest as well as his original opponent benefitted from his misfortune.

The most outstanding benefit to be derived from gaming is that the game may be structured in such a vast variety of ways that it stimulates creative thinking about the competitive situations in which business and military men may find themselves. Indeed these gaming techniques are often powerful aids to intuition and understanding.[23]

Game theory displays a weakness in that it is essentially pure theory which has not yet found extensive application in the solution of practical problems. One reason for this failing is that when the constraints on the game are relaxed drastically (e. g. permitting hundreds of players to become involved in thousands of variable interactions) the mathematical operations become unmanageable despite the fact that, in theory, solutions are attainable.

It cannot be denied however, that game theory has found valuable application in war gaming. War gaming has been used throughout modern history not only as training or heuristic device but also as a device for developing tactics and for determining the effectiveness of combat formations and equipment. Another important contribution of game theory was the impact which it had on the development of linear programming. Linear programming and its extension, dynamic programming, will be addressed in the following section.

---

[23]E. S. Quade (ed.), Analysis for Military Decisions, p. 80.

Linear and Dynamic Programming

It has been noted repeatedly that operations research seeks to optimize the management function through the application of quantitative analysis techniques. It is not surprising then, to learn that very early in the development of the discipline of management science that differential and integral calculus were called upon to help answer the questions of maximization and minimization of functions. Calculus is ideally suited to cope with such problems. Why then has calculus not persisted in the forefront of modern analytical methodology? A few brief reasons are presented by way of introduction to the programming techniques which followed in the wake of calculus' inability to cope with modern management problems. First, classical calculus, like game theory, can theoretically handle a vast array of optimization problems; however, because of the present complexities of business and military problems, classical calculus techniques are either extremely time consuming or untractable. Further, calculus cannot conveniently impose restrictions upon the ranges of the independent variables, thus it produces many answers which are far outside the "ball park" of practical applicability. And finally, classical calculus methods can deal effectively only with equations and many modern variable relationships take the form of inequalities rather than equations.[24]

---

[24]From a lecture given by Dr. Wilfred J. Westlake, Booz - Allen Applied Research, Inc., at the U.S. Army Command and General Staff College on 7 March 1968.

Linear programming which grew out of the investigations of game theorists can be defined as " . . . a technique for maximizing or minimizing a function of a number of variables which are related in a linear fashion and are limited by linear constraints."[25] This technique has found very valuable application in solving problems rapidly (with the aid of electronic computers) which could not be handled, for the reasons stated, by classical calculus. Linear programming is most valuable in determining the best (or optimum) allocation of limited resources. Some outstanding examples of optimization problems which have been successfully solved employing linear programming techniques are:

1. Transportation problems. Given a large number of storage locations and large number of destinations, linear programming can suggest the routing which will minimize cross-haul, oversupply or shortage and thus minimize total transportation costs.

2. Product mix problems. Given that a manufacturer can make two products each of which sells for a different price and require a different allocation of resources (labor, raw materials, time, etc.) to produce. Linear programming can provide him the combination of input and output variables which will maximize his profit.

3. Inventory problems. Given the price of raw materials, the selling price of manufactured goods, and the cost of storing both raw materials and finished goods, linear programming can assist in deciding on the optimum inventory policy.

---

[25] *Loc. cit.*

How then does linear programming fail the systems analyst? Apparent from its name, linear programming is unable to cope with variables which are related in a fashion which is anything other than linear. Unfortunately, a great many complex business and military problems contain such non-linear relationships between the variables.

It was to cope with these non-linear relationships that dynamic programming was devised. Dynamic programming provides (through an ingenious mathematical strategem) a technique for dealing with multi-stage optimization processes. In brief, the dynamic programming technique takes into account the dependence of succeeding stages of a process upon the decisions made in the stage which preceded them.[26] Such complexities are incapable of analysis by linear programming techniques. Dynamic programming is applicable to the same type of problems as is linear programming with the additional application to those problems which are complicated by the existence of non-linear functions.

Both of these programming techniques possess the same inherent weaknesses. Both techniques are heavily computer dependent since they must perform multitudes of arithmetic and algebraic operations in their optimization processes. Finally, because both systems are based on mathematical logic it is easy for an analyst or a manager to accept the results of these programming techniques blindly and uncritically. To do so would be a serious misuse of these

---

[26] Johnson, *et al.*, *The Theory and Management Systems*, p. 222.

management methods, the purpose of which is to aid the manager in making judgmental decisions not to relieve him of the responsibility for doing so.

Methodology

In this section some of the methodology which is an inseparable part of the application of the aforementioned Operations Research/ Systems Analysis techniques will be discussed briefly to show how these essentially theoretical and mathematical techniques contribute to the accomplishment of problem solutions.

The Scientific Method

Various listings are available for the steps to be followed in the scientific method. The following listing suggested by Johnson, *et. al.*, is offered as a starting point for the discussion.

1. Define the problem.
2. State Objectives.
3. Formulate hypotheses.
4. Collect data (empirical verification).
5. Classify, analyze and interpret.
6. Draw conclusions, generalize, restate or develop new hypotheses.[27]

More important than this listing, which is generally understood, is the spirit of the scientific method which the analyst must take with him as he approaches management problems scientifically.

---

[27] Johnson, *et. al.*, *The Theory and Management of Systems*, p. 213.

The spirit is demonstrated by a reverence for facts and an avoidance of assumptions and presumptions. In the application of Operations Research/Systems Analysis techniques, as in the application of other scientific methods, the analyst (experimenter) must be willing to discard hypotheses which cannot be verified and to resume his search anew. The patience which is characteristic of the physical scientist must also be a part of the make-up of the operations researcher/ systems analyst. Moral courage is another trait which must be possessed by both the scientist and the practitioner of modern analytical methods. In this connection, as was mentioned in Chapter II, under the heading of "Pitfalls," the analyst must present his findings candidly even if they be opposed to the announced "party line" of the company or organization. From a practical standpoint, such parochialism may be avoided by employing analysts from outside the organization to be studied or by employing an interdisciplinary team to conduct your operations research.

Interdisciplinary Team

One of the most unique and valuable features to be found in the Operations Research/Systems Analysis methodology since shortly before World War II is the interdisciplinary team. Why was it deemed necessary to create a research team from individuals possessing talent and experience from such diverse fields as: physiology, physics, astrophysics, the military and mathematics to cope with operational problems presented by air raids over

England?[28] The need is expressed quite aptly by Churchman:

> New and improved solutions to problems arise only when the problems are seen in a new light and when new techniques of analysis and solution are applied to them. The team approach assures O. R. [Operations Research] of the necessary new viewpoints and problem-solving techniques.[29]

There are many worthwhile side effects which accrue from the use of the operations research team. As was mentioned earlier, the team can afford to be quite objective in its investigations and quite candid in the announcement of its findings. If properly constituted, oriented and introduced to the members of the organization/operation under analysis, the team should secure the respect and the trust of all individuals concerned; management and labor force alike. The orientation phase cannot be over-emphasized. For a team member to enter an organizational unit and announce that he has been hired to "straighten this place out," will only engender resentment and will negate any good that could have been gained through the application of his scientific or analytical talents. In the next section of this chapter, the steps taken by this interdisciplinary team in the conduct of operations research will be briefly sketched.

Phases of Operations Research

As is true with most attempts to find common terminology in this budding field of Operations Research/Systems Analysis, complete agreement upon the phases that constitute operations research is lacking. However, Churchman offers what he considers

---

[28]McCloskey & Trefethen (eds.), Operations Research, p. 6.

[29]Churchman, et. al., Introduction to Operations Research, p. 57.

to be the major phases of an operations Research project upon which most practitioners would agree. These phases are:

1. Formulating the problem.

2. Constructing a mathematical model to represent the system under study.

3. Deriving a solution from the model.

4. Testing the model and the solution derived from it.

5. Establishing controls over the solution.

6. Putting the solution to work: implementation.[30]

Notice how closely these phases coincide with the scientific method and classical problem solving methods. Two apparent differences are noteworthy; however, and they will be discussed in turn.

Constructing a Mathematical Model

One may say to himself that in conventional problem solving there is no model construction, as such. This initial impression should be investigated further.

The mathematical model referred to here is merely an expression of the effectiveness of the operation being analyzed as a function of variables involved, with at least one of the variables being controllable. This model can be expressed as:

$$E = f(x_i, y_j)$$

Where E represents the effectiveness of the operation, x_i the variables

---

[30] *Ibid.*, p. 13.

of the operation which are controllable, and y_j those variables which are not controllable.[31]

Are the differences between this method and classical problem solving techniques so great? To answer that question consider, for example, the mental process a rational person goes through when he recognizes a problem that requires an immediate solution. A mental model is formed and contains (whether consciously or unconsciously) all the elements of the mathematical model. Courses of action flash through one's mind, the success or failure of which depend upon variables which either can or cannot be controlled by the problem solver. A decision is reached and the model is tested when the action is taken. A man observes a baby trapped in a burning building. The fire is raging out of control. The man knows he can't put the fire out; but, he also knows that he is a fast runner. He dashes into the building, extricates the baby before the roof collapses and proves the effectiveness of his mental model.

Establishing Controls Over the Solution

This apparent difference can be explained quite readily by considering a hypothetical scientific break-through scored in a physics laboratory. This break-through may represent the solution of a knotty problem which had been perplexing scientists for ages. However, the application of this solution to the same problem outside the laboratory may have to be constrained because it is too costly to be applied on other than the laboratory scale. The possibility

---

[31] *Ibid.*, p. 13.

exists that the solution may be automatically constrained in that it may not have been developed sufficiently to be effective outside of the controlled laboratory conditions.

An operations research project conducted through the phases listed and employing sound scientific techniques should yield the best possible data upon which the manager can base his decisions. Thus, methodology serves as the vehicle which brings the mathematical and statistical techniques to bear on the solution of management problems.

Summary

In this chapter some of the more common mathematical and statistical techniques which find application to Operations Research/ Systems Analysis were investigated. As each of the techniques was discussed, an indication was given as to the particular strengths and weaknesses of those techniques. The types of problems to which each of these techniques are applicable were cited. Finally, the methodology which is used to apply the techniques to the problems to be solved was sketched briefly. In Chapter IV, the materiel development cycle currently in use in the United States Army will be presented and thoroughly investigated.

CHAPTER IV

MATERIEL DEVELOPMENT PROCESS: HYPOTHETICAL SURFACE-TO-SURFACE MISSILE SYSTEM

Introduction

In the preceding two chapters the general nature of Operations Research/Systems Analysis and some mathematical and statistical techniques employed in modern management were presented. In this chapter the procedure through which a new missile system is introduced into the Army inventory will be investigated.

To establish a media through which the development process may be discussed, a hypothetical weapon system will be described. The investigations will proceed with a treatment of the materiel development process to include a discussion of the phases of the development process; namely, concept formulation, contract definition, development and production, and operations and disposal. Included in this discussion will be a study of the primary agencies which are responsible for the accomplishment of materiel development. In particular, the Operations Research/Systems Analysis activities of each of these agencies will be exposed as a basis for the discussion in Chapter V of the application of Operations Research/Systems Analysis techniques to the materiel development process within one particular agency. The commands and offices to be investigated herein will be:

1. U. S. Army Materiel Command.
2. Project Manager.

3. U. S. Army Combat Developments Command.

4. Office, Assistant Vice Chief of Staff, U. S. Army.

The detailed investigation into the materiel development process will continue with a review of the management models in use at various levels of command throughout the Army. Present application of Operations Research/Systems Analysis techniques within the framework of these models will be presented. This portion of the chapter will rely on current Department of the Army regulations, procedures and methodology as source materiel.

As the development process is explored, the management activities inherent in the various phases will be isolated and clearly defined. Those activities, especially those involving executive decisions, which are particularly critical will be identified. It is at these critical decision points that Operations Research/Systems Analysis is likely to find its greatest application since the techniques which it employs are intended to provide the decision-maker with the best possible data upon which to base his decision.

Description of a Hypothetical Missile System

It is necessary at this time to briefly describe the characteristics of a hypothetical missile system, the CATAPULT. Such a description is deemed necessary so that the relationship of the system parts to the system as a whole can be clearly understood.

The CATAPULT is a supersonic, surface-to-surface, inertially guided missile system intended to replace LANCE as a division support weapon during the 1980-85 time period. The CATAPULT missile is capable of attacking targets .5 miles to 50 miles distant from its

mobile launcher. Thus, like its historical ancestor from which it obtained its name, the CATAPULT enables the commander to project his combat power to great distances with improved accuracy. The name appropriately describes the functioning of the system in that the CATAPULT employs a revolutionary propulsion system which converts the earth's ambient magnetic energy into useful propulsive force. The employment of this concept simplifies the propulsion system to such an extent that essentially only the warhead and guidance instruments move from the launcher to the target area. The destructive punch of the CATAPULT missile system is provided by a variety of warhead options: conventional high explosive, nuclear, chemical, biological and special.

As the discussion of the development of this weapon system unfolds the interrelationship of the agencies responsible for such components as the mobile launcher, the air frame, the propulsion system (magnetic converter), the guidance system, and the warhead will be explored. Other agencies will be identified as they enter or leave the development cycle as it proceeds chronologically from concept formulation to disposal.

Since the CATAPULT will be used to fulfill a land combat role, it is assumed that the U. S. Army will have the overall responsibility for system development. Therefore, in the following section a compendium of the Army's materiel development process will be presented.

Materiel Development Process

General

A presentation of every detail of the materiel development process is neither feasible in a study of this length nor would such a

detailed presentation fall within the scope of the thesis as outlined in the introduction. However, a sketch of the development process is essential to an understanding of the possible application of Operations Research/Systems Analysis techniques which will be developed in the following chapter.

The materiel development process begins with the recognition of a future military threat and a decision to produce some item of materiel to counter the threat which has been recognized. At times, significant technological break-throughs may initiate the development of new equipment if it is believed that the application of the scientific innovation will result in a vast improvement in capability over materiel presently in use or under development. The development of the CATAPULT system was prompted by such an occurrence. Ideas for new materiel come from three sources; the user of present equipment (as represented by U. S. Army Combat Developments Command), industry and private inventors, and government laboratories.[1] These ideas must be given purpose, direction and guidance for them to be useful. Further, it is important that the materiel to be developed be capable of countering the threat as identified in the Basic Army Strategic Estimate and that the development proceed in accordance with the priority operational requirements set forth in the Army Strategic Plans. A document exists within the development framework which provides the necessary guidance. It is the Combat Development Objectives Guide and it will be discussed in detail in the following paragraph.

---

[1]U. S. Army Command and General Staff College, CONUS Logistics and Combat Service Support, RB 101-3, (Fort Leavenworth, Kansas: 1967), p. 7-3.

Combat Development Objectives Guide

The Combat Development Objectives Guide (CDOG) is developed from the various strategic estimates, plans and studies which are accomplished at Department of the Army level. It is a key document in the materiel development process and is described in Field Manual 38-7 as follows:

> This guide is a Department of the Army publication which defines those operational and organizational objectives and concepts, materiel developmental objectives, and materiel requirements that are approved. It serves as both a guidance and control document. It provides guidance to all developing agencies in research and development planning and decision-making activities of that command.[2]

A listing of some of the approved documents which the CDOG contains, and an explanation thereof, will further emphasize the importance of this publication. The chapters of the CDOG are divided into sections which identify the operational capabilities objectives (OCO) and qualitative materiel development objectives (QMDO) and consolidate those studies, field experiments, and qualitative materiel requirements (QMR) which are directed toward the attainment of the OCO and the QMDO.[3] The operational capabilities objective (OCO) is defined as:

> A Department of the Army approved description (qualitative to the extent practicable) of an operational capability desirable of achievement primarily in the long-range time frame (10-20 years in the future).[4]

---

[2]U. S. Department of the Army, Materiel Development Management, FM 38-7 (Washington: U. S. Government Printing Office, 1966), pp. 5-6 and 5-7.

[3]U. S., Department of the Army, Army Combat Developments, AR 71-1 (Washington: U. S. Government Printing Office, 1966), p. 8.

[4]U. S., Department of the Army, Materiel Development, FM 38-7, p. 5-7.

A qualitative materiel development objective (QMDO) is:

> A statement of a Department of the Army military need for developing new materiel, the feasibility or specific definition of which cannot be determined sufficiently to permit establishing a qualitative materiel requirement.[5]

The definition of a qualitative materiel requirement, which is needed to complete the meaning of the previous definition, also completes the identification of the three most important materiel development documents found in the CDOG. From the same source as above, a qualitative materiel requirement (QMR) is "A definitive statement of a Department of the Army military need for a new item, system or assemblage, the development of which is believed feasible."[6]

Sequence of Materiel Development Actions

One can see in the progression through these objectives and requirements documents that the proposed materiel system is becoming more clearly defined. To illustrate how this progression would occur in practice it will be helpful to turn again to the hypothetical CATAPULT missile system and to trace the steps in its development to date (1968) and to analyze the time phasing of the actions remaining to be accomplished before it is introduced into the Army arsenal of weapons. The sequence of actions in the materiel development of the CATAPULT can best be explained by reference to the

---

[5] U. S. Department of the Army, Army Research and Development, AR 705-5 (Washington: U. S. Government Printing Office, 1964), p. 4.

[6] Ibid.

Army Combat Development Program.[7] In a recent publication of AR 11-25 the following definition of the Army Combat Development Program is given:

> A series of time-phased implementing programs designed to facilitate the development and integration of new or improved doctrine, materiel and organization into the Army in the field during a designated implementation period . . .[8]

The Army Combat Development Program assists the U. S. Army Combat Developments Command in answering the questions: How should the Army fight? How should the Army be equipped? How should the Army be organized? Since this chapter concerns itself only with the materiel development process, the ensuing discussion will be addressed to the materiel portion of the Army Combat Development Program (i. e., how the program assists in answering the second of the above listed questions). The discussion will be limited further in that it will only consider the development of the CATAPULT; whereas, in practice numerous materiel items would be under consideration simultaneously.

The materiel development cycle spans a 20 year time interval which is subdivided into four periods each of five year's duration. During the five year period following the completion of development, the program is being implemented with the introduction of the new

---

[7]The term "Army Combat Development Program" replaced the familiar term "Army Concept Program" effective with a letter, Headquarters, United States Army Combat Developments Command, subject: Change in Term - "Army Concept Program," dated 15 April 1968.

[8]U.S., Department of the Army, <u>The Management Process for Development of Army Systems</u>, AR 11-25 (Washington: U.S. Government Printing Office, 1968), p. 8.

item of materiel. Thus, the Army Combat Development Program, Army-85, began its development in 1960 and is to be implemented during the 1980-85 time period.[9]

Since it is planned to introduce the CATAPULT into the Army inventory beginning in 1980 it is necessary to go back to 1960 in tracing its development. Based on the technological forecast that the CATAPULT could be deployed in 1980 with a vastly superior and revolutionary propulsion system it was approved as a concept and an operational capability objective (OCO) was prepared during the 1960-65 time period. With the necessary funds and other support being provided the development continued during the period 1965-70 and at present (1968) a proposed qualitative materiel development objective (PQMDO) is being prepared. It is necessary to prepare a QMDO because, although theoretically possible, the present state-of-the-art does not assure the feasibility of the system becoming operational in the field by 1980.

Assuming that subsequent research discloses the feasibility of the CATAPULT missile system approach, a qualitative materiel requirement (QMR) would be prepared during the 1970-75 time period outlining to the developing agency the characteristics of the system required by the user. This requirement must be stated as a QMR because the CATAPULT project will entail $2.5 million or more of development costs and $10 million or more of production costs

[9]U.S., Department of the Army, Materiel Development, FM 38-7, p. 6-7.

(requirements for projects of a lesser magnitude may be expressed as a small development requirement).[10] Further, it is important to note that the ultimate development of the CATAPULT missile system is expected to cost $25 million in research funds or $100 million in production funds. In such a case, the development must be project managed and must undergo contract definition.[11] This requirement will be discussed in greater detail in subsequent sections of this chapter.[12]

While the developing agency proceeds with the development of the hardware components of the CATAPULT missile system, the necessary documentation (Tables of Organization and Equipment, Field Manuals, etc.) is being prepared concurrently during the 1975-80 time period.

Thus, we reach the end of the development cycle for the CATAPULT missile system and assuming the successful development, the system would be deployed to divisions in the field starting in 1980. A graphical portrayal of this sequence of materiel development actions is shown in Figure 1.

The development of the hypothetical CATAPULT missile system has been isolated herein to facilitate analysis and investigation. It should be remembered that in reality this program would be but a single part of a continuous succession of overlapping programs at

---

[10] Ibid., p. 6-6.

[11] U.S. Army Combat Developments Command, USACDC Procedural Management Model, A Command and Staff Guide (DRAFT) (Fort Belvoir, Virginia: 1968), p. 11a.

[12] See pages 70 and 77.

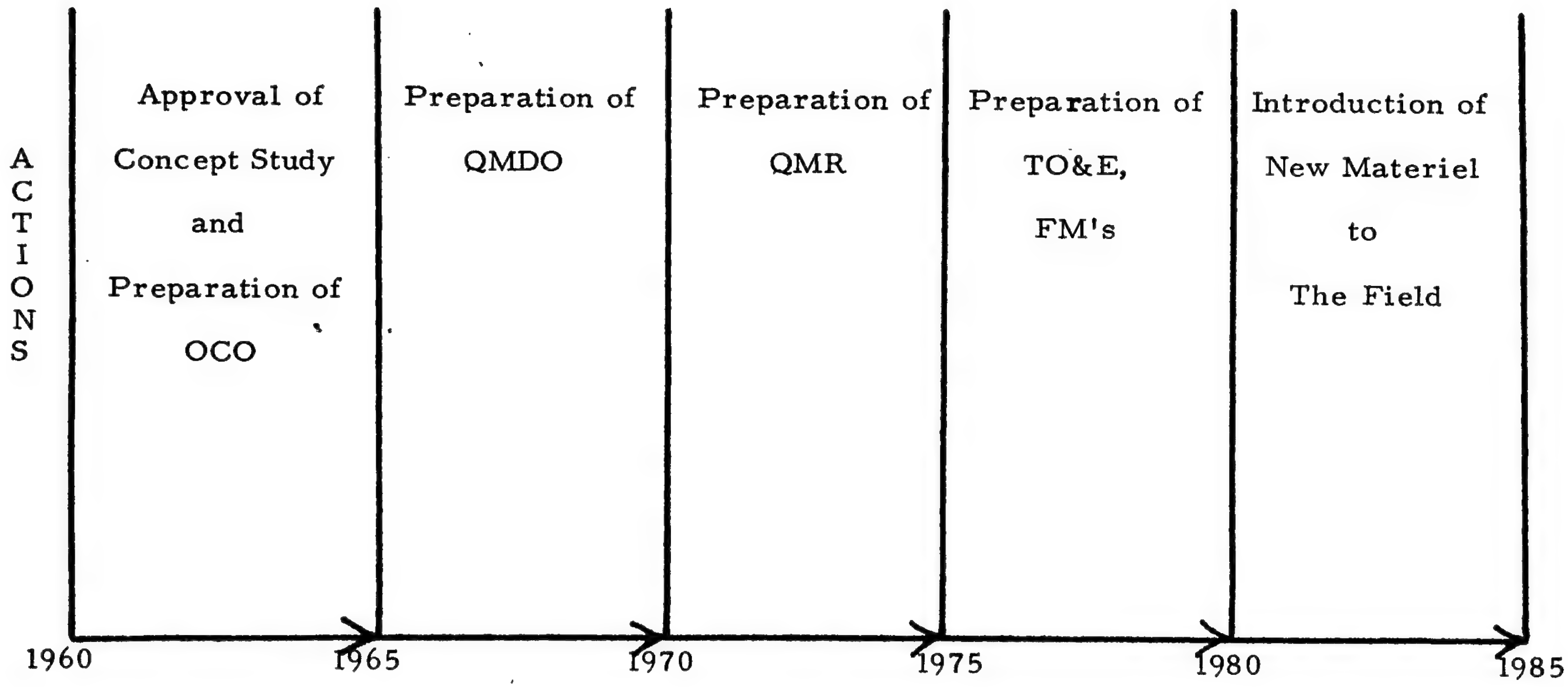

Figure 1. Sequence of Materiel Development Actions - Army Combat Development Program, Army - 85

different stages of development throughout the entire 25 year period under study. In the following section of this chapter the phases of the developmental process which have been identified by the Department of the Army and the U. S. Army Combat Developments Command will be discussed.

Phases of the Developmental Process

Superimposed on the sequence of actions necessary to bring an idea to fruition in the form of hardware on the battlefield; and extending to the disposal of an item at the end of its useful life-cycle is the structure of the phases of the developmental process. These phases are defined somewhat differently by the Department of the Army and the U. S. Army Combat Developments Command but the differences represent changes in titles only and are not substantive.[13] A brief review of each is given for comparison.

The phases of the development process to which the Department of the Army subscribes are those listed in the introduction to this chapter, i. e., concept formulation, contract definition, development and production, and operations and disposal.[14] The U. S. Army Combat Developments Command (USACDC) has renamed three of the four phases to better describe the command's effort during those phases.[15]

---

[13] U. S. Army Combat Developments Command, Procedural Management Model (DRAFT), p. 3a.

[14] U. S., Department of the Army, Model for Management of the Life-Cycle of Materiel Systems, approved by the Army Chief of Staff on 21 March 1967.

[15] U. S. Army Combat Developments Command, Procedural Management Model (DRAFT), p. 3a.

The four phases of the developmental process as defined by USACDC are: concept formulation, system definition, production and operations.[16]

The USACDC developmental process will now be discussed in greater detail for the following reason. In the next chapter of this thesis the possible incorporation of Operations Research/Systems Analysis techniques into the Institute of Combined Arms and Support's (ICAS) management model will be investigated. Since the ICAS model was derived from the USACDC developmental process, a discussion of the phases of that process at this time will provide a valuable foundation for subsequent investigation.

PHASE I - Concept Formulation

During this phase a number of important steps in the sequence of materiel development actions are accomplished. After an analysis and review of alternative conceptual designs to satisfy future materiel needs, USACDC subordinate elements prepare a draft operational capabilities objective (OCO). As described earlier, when the OCO is approved, exploratory development, so guided, may proceed. Derivative studies[17] are then undertaken which ultimately lead to the preparation of a proposed qualitative materiel development objective (PQMDO) after having been subjected to numerous in-process reviews

---

[16] Ibid., pp. 4a - 5a.

[17] AR 71-1, Army Combat Developments, defines a derivative study as " . . . a combat development study based on an approved doctrine study for a designated time period which develops branch or functional area doctrine for the Army in the field. "

along the way. When the QMDO is approved, advanced development by the developing agency may proceed. As this development progresses, the developing agency offers materiel trade-offs to USACDC for evaluation. At this point, Operations Research/Systems Analysis techniques are used to assist USACDC in making the trade-off evaluation in the best interest of the user which USACDC represents. The materiel approach selected by the developing agency after the trade-off evaluation then proceeds through a cost-effectiveness analysis to USACDC for preparation of a proposed qualitative materiel requirement (PQMR). After the QMR is approved by Department of the Army, three other important steps must take place before the materiel developmental process may proceed into Phase II. Since a large, high cost project is assumed; preparations for system (contract) definition, preparation of the Project Manager's charter and the first of five materiel status evaluations (MSE)[18] must be accomplished.

Thus ends the Concept Formulation Phase. It is readily apparent that this phase has encompassed the first three segments of the 25 year Army Combat Development Program (See Figure 1).

PHASE II - System Definition

This phase involves the search for the most capable contractor to perform the development and the most feasible technical approach to the satisfaction of the qualitative materiel requirement (QMR). The developing agency solicits proposals from interested contractors,

[18] Materiel status evaluations are check points at which determination is made as to whether or not development should continue.

forwards the most deserving one to Department of the Army for evaluation and approval, and eventually negotiates the final contracts, (during Phase III).

During Phase II there is another important trade-off determination which must be made. Herein, the contractor suggests characteristic trade-offs and USACDC, again employing Operations Research support, makes a trade-off evaluation in the light of the user requirements. The contract definition materiel status evaluation (MSE) is performed during this phase and favorable evaluation of the status permits an updating of the QMR by USACDC. The updated QMR serves as a basis for a revision of the materiel development plan by the developing agency if such revision be necessary. Recommendations as to the acceptable technical approach and contract developer are forwarded from Department of the Army level to the Office of the Secretary of Defense for final approval. Insofar as the materiel development portion of the overall development process is concerned, system definition ends when contract definition is accomplished. When all of the above actions are completed, the development may proceed into the Production Phase.

PHASE III - Production

It should be understood that in the early portion of the production phase, the majority of the effort is being expended by the developer and not the producer (the producer will not be selected until the development has undergone two additional materiel status evaluations). In fact, the completion of a prototype of the system by the developer

provides the basis for one of these two evaluations (the third MSE in the cycle).[19]

However, during the early portion of this phase preparations are being made for the awarding of the production contract. These preparations include the awarding of the development contract, the securing of real estate and facilities and the accomplishment of such ancillary preparations as literature planning and planning for appropriate personnel skills.

Another materiel status evaluation (MSE) (the fourth in the cycle), the Development Acceptance MSE, is conducted to determine if the awarding of the production contract should be authorized. If all the aspects of the technical development and necessary funding requirements are satisfied, continued development is approved. Only after this milestone is passed can the production contract be awarded. After the production contract is awarded and production begins, production acceptance tests ensue. When the production acceptance tests are passed and necessary changes are made to the doctrinal literature the new materiel is subjected to an inter-command materiel status evaluation (the fifth and normally the final). The purpose of this MSE is the "revalidation of the requirement and determination that the new item/system can serve the purpose for which it was designed."[20] This action provides the basis for final type classification;

---

[19] U.S. Army Combat Developments Command, Procedural Management Model (DRAFT), p. 16.

[20] Ibid., p. 19a.

however, the production phase does not end until the first unit is equipped with the new materiel and begins training.

PHASE IV - Operations

During this phase almost the entire materiel responsibility is vested in the appropriate commodity command of the developing agency. Feedback from the field provides the basis for revisions to Field Manuals and Tables of Organization and Equipment by the USACDC. The commodity command has the responsibility for providing the field service to the units equipped with the new materiel and plans for modifications, retrofit and eventual disposal of the materiel as it is replaced by the follow-on generation of equipment.

In the paragraphs which follow, the agencies responsible for the various aspects of the materiel development process will be studied. Those agencies which have specific Operations Research/ Systems Analysis capabilities and missions will receive particular emphasis.

Responsible Agencies

It should be apparent from the foregoing review of a small segment of the Army's materiel development program that the complexity and magnitude of the tasks involved preclude a single agency from being able to effectively manage the overall development program. However, through the judicious division of responsibilities among several agencies the tasks can be reduced to manageable proportions. It will be shown that even the Project Managers who have overall responsibility for their respective projects are only

concerned with a rather narrow portion of the entire materiel management effort within the Army.

U. S. Army Materiel Command

As the materiel development process was outlined above, the unnamed "development agency" was seen to be a primary element in the development process. The agency being referred to was the U. S. Army Materiel Command (USAMC). It was not identified at that time for the sake of simplicity for although USAMC has the responsibility for the bulk of the Army's materiel development it does relinquish certain specialized projects to be developed by the U. S. Army Security Agency, the U. S. Army Strategic Communications Command, the Surgeon General, and the Chief of Engineers in their respective areas of interest.[21]

The responsibilities of the U. S. Army Materiel Command in the area of materiel development is set forth in FM 38-7 as follows:

> The Army Materiel Command is responsible in assigned areas for research, development, engineering, test and evaluation, procurement, production, and logistics support of Army materiel. The materiel development responsibility of the Army Materiel Command is carried out by the commodity commands - Electronics, Missiles, Weapons, Mobility and Munitions - with central coordination at Headquarters, Army Materiel Command.[22]

To illustrate the manner in which the commodity commands become involved in the materiel development process consider, once again, the hypothetical CATAPULT missile system. Which commodity

---

[21]U. S. Department of the Army, The Management Process for the Development of Army Systems, AR 11-25, pp. 5-6.

[22]U. S. Department of the Army, Materiel Development, FM 38-7, p. 2-2.

commands would have an interest in the development of such a weapon system? The answer to that question can be found in an investigation of the missions of the commodity commands as they relate to the subsystems which comprise the CATAPULT missile system. Taking the subsystems (greatly simplified) in turn:

The Mobile Launcher

The commodity command exercising management over this subsystem cannot be determined without first knowning the nature of the launcher. Is it a wheeled vehicle? Or is it a tracked vehicle which when carrying the CATAPULT missile may be considered a combat vehicle? If it is a wheeled vehicle then the U. S. Army Mobility Command would have management responsibility. If, however, the launcher is a combat vehicle the U. S. Army Weapons Command has the management assignment.[23]

The Missile Air Frame and Guidance System

There is little doubt as to the responsible commodity command for the development of these components since the U. S. Army Missile Command has the specific assignment to exercise commodity management of free rockets, guided missiles, ballistic missiles, etc.[24] Which agency; however, is responsible for insuring compatability between the configuration of the launch vehicle and the configuration of the missile air frame; or the compatibility of the electrical

[23] U.S., Department of the Army, United States Army Materiel Command, AR 10-11 (Washington: U.S. Government Printing Office, 1965), p. 4.

[24] Ibid.

connectors between the power source and the guidance package?

The Propulsion System

Because of the revolutionary electromagnetic nature of this exotic propulsion system, will it be managed as a conventional rocket engine by the U. S. Army Missile Command or will it be construed to be electric power generation equipment and be assigned to the U. S. Army Electronics Command for management?[25]

The Warhead

Intrasystem compatibility is the only apparent problem here since the U. S. Army Munitions Command has the clear-cut assignment of ". . . integrated commodity management of nuclear and nonnuclear ammunition; rocket and missile warheads; chemical, biological and radiological materiel . . ."[26]

These simple examples illustrate the actual problems which confront materiel developers. The managers of these development projects within the USAMC solve their problems employing essentially classical management techniques. There is not an Operations Research/Systems Analysis responsibility specifically identified, as such, in the mission statement of the USAMC.[27] That is not to say, however, that certain management innovations, which have come to be identified with the modern analytical techniques, are not used. For example, the program evaluation and review technique

---

[25]<u>Ibid.</u>

[26]<u>Ibid.</u>, p. 4.

[27]Ibid., p. 1.

(PERT) and configuration management are in general use throughout the materiel development activities of the Army.[28] Regardless of the techniques employed, there must be a mediating headquarters or agency to make interpretations such as those presented in the foregoing hypothetical example, an agency which can reconcile differences without becoming so deeply involved in the operational aspects of the development that it loses its potency as a mangement activity. The project manager with his project management office provides such an agency.

Project Manager

A project manager is: "An individual designated by the Secretary of the Army who is assigned the responsibility and delegated the full line authority for the centralized management of a specific project."[29]

With this centralized responsibility, the project manager is also provided with the control over the resources necessary to effectively manage the specific project which he has been assigned. In one respect he can focus his attention acutely on his project to the exclusion of the conflicting interests which surround him.

In brief, project management is mandatory for projects of great military urgency or high development and production costs.[30] Other

---

[28] U.S., Department of the Army, Materiel Development, FM 38-7, p. 2-2.

[29] U.S. Department of the Army, System/Project Management, AR 70-17 (Washington: U.S. Government Printing Office, 1968), p. 1.

[30] The threshold which defines a high cost project was presented on page 66.

projects may be designated for project management by the Secretary of the Army.

As was true in the case of the U. S. Army Materiel Command, there is no specific requirement for the project manager to employ Operations Research/Systems Analysis techniques, as such, in the management of his project. The project manager is, however, specifically required to:

> Use management models and techniques to - Amass and project costs . . . Assist design engineers and system support planners to keep equipment design compatible with the conditions and concepts that will prevail at the time of equipment distribution . . . Prescribe an internal reporting system that will assess equipment availability, identify deficiencies and form a data base for effectiveness assessment for use in cost effectiveness trade-off studies. . . .[31]

Thus, it can be seen that the employment of modern analytical techniques is implied and that the project manager could use Operations Research/Systems Analysis to good advantage in the management of his specific project. The capability to perform Operations Research/Systems Analysis is not specifically provided the project manager.[32]

U. S. Army Combat Developments Command

The responsibilities of the U. S. Army Combat Developments Command (USACDC) in materiel developments were covered in sufficient detail in preceeding sections of this chapter as to only

---

[31] U.S., Department of the Army, System/Project Management, AR 70-17, p. 6.

[32] Ibid., p. 7.

require a brief review at this time. As stated in AR 10-12 the principal materiel development functions of USACDC are to:

> Develop, test, and recommend improved operational, organizational and doctrinal concepts for the Army in the field. . . . Develop and recommend operational, organizational, and doctrinal concepts for the Army of the future. . . . Prepare recommendations with regard to - Revisions of the Basic Army Strategic Estimate, the Army Strategic Plan, and the Army Force Development plan. Revisions of the Combat Developments Objectives Guide. Establishment, revision and/or elimination of qualitative materiel development objectives, qualitative material requirements. . . .[33]

Further, and perhaps the most important function of the USACDC in the area of materiel development is its responsibility for monitoring of the research and development activities to insure that the development will achieve the intended objectives. USACDC represents the needs of the user throughout the developmental process.

The Operations Research/Systems Analysis capability within the USACDC is considerable and will be discussed in some detail at each level of command at which the capability exists. This discussion is not intended to be exhaustive but will be restricted to information which will form the basis for the material to be presented in the following chapter.

Headquarters, USACDC

Within the Directorate of Evaluation, the Operations Research Support Division provides a focal point for operations research activities. The division provides no actual operations research support but provides advice and assistance to all CDC subordinate

---

[33] U. S., Department of the Army, United States Army Combat Developments Command, AR 10-12 (Washington: U.S. Government Printing Office, 1965), p. 1.

commands on the acquisition, use and evaluation of operations research and scientific support. This division acts as contracting officer representative for contracts in support of Headquarters, USACDC and manages all contractual scientific effort.[34]

Institute of Systems Analysis

At the time of this writing (1968), the Institute is in its embryonic stages and has not yet begun to function on a full scale basis. The mission of the Institute of Systems Analysis is to " . . . provide a scientific and technical support capability in designated areas for USACDC combat effectiveness and cost analysis studies."[35] It is not intended that the Institute of Systems Analysis be the repository of all Operations Research/Systems Analysis capability within USACDC but rather that the Institute provide operations research support in conjunction with the operations research activities of the various agencies and the USACDC staff.

Institute of Combined Arms and Support (ICAS)

The Analysis and Operations Research Support Branch of the Evaluation Division provides much the same operations research support to ICAS as the Operations Research Support Division provides to Headquarters, USACDC with the addition of providing ICAS with

---

[34]U.S. Army Combat Developments Command, Organization and Functions of Headquarters, USACDC, USACDC Pam 10-2 (Fort Belvoir, Va.: 1967).

[35]U.S. Army Combat Developments Command, Organization and Functions of USACDC Subordinate Commands, USACDC Pam 10-1 (Fort Belvoir, Va.: 1967), p. 2-1.

a limited operations research capability.[36] Additionally, the War Games Branch of the Evaluation Division develops tactical and logistical war games, manages the ICAS war games, and insures compatibility of the war games with the overall Combat Developments Command's programs.[37]

Office of the Assistant Vice Chief of Staff, U. S. Army

This office, established by Chief of Staff Memorandum 67-64 on 16 February 1967 is responsible for an Army-wide study effort aimed at improving performance and effectiveness in all functional areas.[38] It is the Operations Research/Systems Analysis focal point for the Department of the Army. The office has both an in-house and a contract capability for analyzing studies using operations research techniques.[39] However, it provides no operations research support below Department of the Army level.

There are, of course, many other agencies which become involved in the materiel development process; however, the agencies which have been presented make the largest contribution and are those which are applying Operations Research/Systems Analysis techniques

---

[36] Institute of Combined Arms and Support, Organization Mission and Functions Manual, USACDCICAS Regulation 10-1 (Fort Leavenworth, Kansas: 1967), p. 23.

[37] Ibid., p. 25.

[38] United States Army Reorganization of the Office, Chief of Staff, CSM 67-64 (16 February 1967).

[39] Taped interview with Brigadier General William O. Quirey, U. S. Army, Director of Studies, Office of the Assistant Vice Chief of Staff of the Army, Kansas City, Missouri, 25 January 1968.

to the materiel development process or have the potential for doing so. In the following section of this chapter the Materiel Management Models (blueprints for the materiel developmental process) at the respective levels of Department of the Army, U. S. Army Combat Developments Command, and Institute of Combined Arms and Support will be reviewed.

Management Models

Headquarters, Department of the Army, has provided a materiel management model (DAMM) to guide the developmental efforts of its subordinate commands in the pursuit of their materiel developments programs. The general flow of an idea through this model, the conversion of the idea into a piece of military hardware, and the eventual disposal of the obsolete materiel item were presented earlier and will not be reviewed again. The U. S. Army Combat Developments Command extracted from the Army model and portrayed its responsibilities in a USACDC management model. For purposes of viewing the Operations Research/Systems Analysis activities involved in both models, the two may be considered as a single model since there is virtually no difference in the manner in which the Operations Research Support is applied. Since the phrase, operations research support, appears repeatedly in both models an understanding of what such support entails may be in order. The operations research support may take the form of any of the several modern analytical techniques being applied to a complex, and often obscure, decision-making problem and providing the decision maker with the best data upon which to base his decision. The techniques employed

place a great reliance upon statistical analysis and probability theory because these methods are ideally suited for dealing with uncertainties and problems which contain many and complex variables.[40] Support to the decision-maker may also be rendered by providing computer availability to handle the tremendous number of repetitive calculations engendered by complex materiel development problems.[41] Thus, the general statement can be made about both the DA management model and the USACDC management model that Operations Research Support has been introduced where such support facilitates the rendering of a timely and accurate executive decision.

A striking difference is noted when the Institute of Combined Arms and Support management model is viewed. Operations research support is not included in any of the action blocks, yet there appear to be several decision milestones which could benefit from the application of Operations Research/Systems Analysis techniques. Chapter V of this thesis will be devoted to the study of the possible incorporation of Operations Research/Systems Analysis techniques into the Institute of Combined Arms and Support's management model.

The management activities within the materiel developmental process which appear to be particularly well suited to the application of quantitative analysis will be presented in the following section.

---

[40] See Techniques, Chapter III.

[41] U. S., Department of the Army, Materiel Development, FM 38-7, p. 2-2.

Management Activities

Throughout this review of the U.S. Army materiel development process management check points of critical importance were identified. At any point in the process where failure to obtain a decision prevented the progress to the next step a critical management point had been reached. Though many such points have been previously highlighted, the most important of these events are summarized below as a review of the potential bottlenecks in the developmental process, and to provide a ready reference for future investigations.[42]

Analysis of Alternative Conceptual Designs

Trade-off Evaluations

Approval of Parametric Design Studies

Cost/Effectiveness Study and Analysis

Materiel Status Evaluations

Determination of Engineering Feasibility

Development Acceptance Tests

Production Acceptance Tests

Summary

In this chapter a hypothetical missile system, the CATAPULT, was introduced as a vehicle for describing the materiel developments process. The Combat Developments Objectives Guide (CDOG) was described and the interrelationship between the various objectives and requirements documents (OCO's, QMDO's and QMR's) found in the

---

[42] U. S. Army Combat Developments Command, Conceptual Management Model (DRAFT).

CDOG was explained. The sequence of actions necessary to bring a system from the idea stage to battlefield hardware was explained. The time phasing over a 25 year period of the Army Combat Development Program was graphically portrayed.

The phases of the materiel developmental process which are superimposed on the Army Combat Development Program were explored in some detail. The agencies having primary responsibility for the developmental process were studied with particular attention being paid to the Operations Research/Systems Analysis capabilities possessed by each.

The chapter concluded with a brief review of the existing materiel management models and an identification of the critical decision check points within the models. In the following chapter the findings of Chapters III and IV will be synthesized into a single investigation of the possible incorporation of the techniques of Operations Research/Systems Analysis into the Institute of Combined Arms and Support's management model.

CHAPTER V

INCORPORATION OF OPERATIONS RESEARCH/ SYSTEMS ANALYSIS

Introduction

In Chapter IV the materiel development process was described using, in part, a hypothetical missile system to explain the procedure. As the development process was exposed, certain critical decision check points were identified. In this chapter, the techniques and methodology of Operations Research/Systems Analysis which were introduced in Chapter III and the developmental process which was outlined in Chapter IV will be synthesized into a suggested policy for incorporating these techniques into the management model which guides the Institute of Combined Arms and Support (ICAS) in the accomplishment of its functions and tasks in the developmental process. In this chapter the missions and functions of ICAS will be presented and through a review of the ICAS management model, critical management check points will be identified. An investigation will ensue of the applicability of Operations Research/Systems Analysis techniques to these management check points to provide the manager the best data upon which to base a decision. If more than one technique has applicability to any particular decision point, the techniques will be arranged in order of their suggested suitability. Finally, a policy will be suggested for incorporating these techniques into the ICAS

developmental methodology. This policy will suggest the functions to be performed and the organizational elements, be they within the Institute or out-of-house, responsible for the application of Operations Research/Systems Analysis to the process.

The material for this chapter has been drawn, to a large extent, from personal interviews with presently assigned ICAS operating/action personnel during the period January to May 1968. As will be described in more detail subsequently, the procedures outlined herein are essentially theoretical in that sufficient time has not elapsed to fully implement the procedures in practice.[1] Documentary evidence of the success or failure of the present methodology is nonexistent or, at best, scanty; thus, personal interviews and informal staff papers had to be heavily relied upon as primary sources of information.

Institute of Combined Arms and Support

General

The Institute of Combined Arms and Support is a major subordinate headquarters of the U. S. Army Combat Developments Command (USACDC) with the Commanding General of ICAS reporting directly to the Commanding General, USACDC. The relationship of ICAS to the other organizational elements within the U. S. Combat Developments Command can be seen in a simplified USACDC organization

---

[1]See page 90.

chart shown in Figure 2.[2] The role of the Institute of Combined Arms and Support in the development of the Army of the future will be presented in the following paragraphs.

Recall, from the preceding chapter,[3] that the U.S. Army Combat Developments Command is charged with the responsibility of providing the answers to three fundamental questions regarding the Army of the future.

1. How should it fight?

2. How should it be equipped?

3. How should it be organized?

The Institute of Combined Arms and Support is responsible for providing a portion of the answers to those important questions as shown in the Institute's mission statement.[4]

> In order to insure the orderly and timely development of Army Concept Programs as unifying concepts for the Army in the field, the USACDC Institute of Combined Arms and Support (ICAS) will accomplish the following tasks:
>
> a. For each Army Concept Program and based on the approved concept study, develop the combined arms and support doctrine study for the Army in the field below Theater Army. In developing doctrine for combat and combat support functions, address the command levels above brigade that combine more than one arm or

---

[2]U.S. Army Combat Developments Command, Organization Mission and Functions of USACDC Subordinate Commands, USACDC Pamphlet 10-1 (Fort Belvoir, Va.: 1967), Change 3, dated 5 Oct 1967.

[3]See pages 64 and 79.

[4]In reading this mission statement it should be remembered that the Army Concept Program has been renamed the Army Combat Development Program. Further, it should be noted that the concept study which serves as the basis for the development of the doctrine study is the Land Combat Systems Study developed by the USACDC Institute of Land Combat.

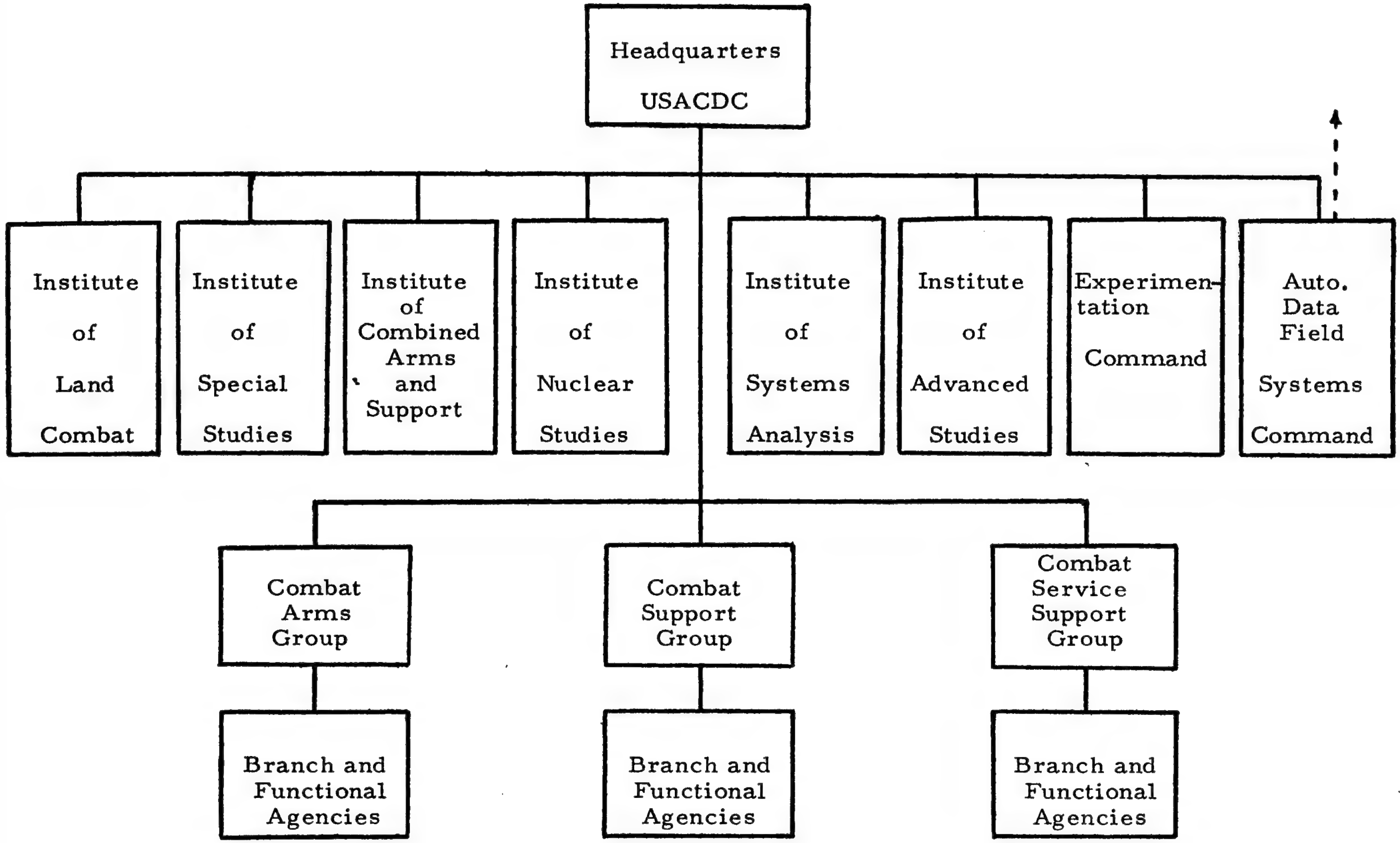

Figure 2. Organization Chart - U.S. Army Combat Development Command

service (branch or function); for the combat service support function, address the command levels above battalion that combine more than one arm or service (branch or function). For both, exclude Theater Army and those units that execute a single arm or service (branch or function) operational role, either unilaterally or on a predominate basis. (EXAMPLES: Artillery groups, engineer brigades, transportation commands, armored cavalry regiments, separate brigades, personnel commands.)

b. For each Army Concept Program, develop fully-rounded operational doctrine, materiel requirements, and organization, and the staffing doctrine, organization, and procedures at the above command levels to include the joint and combined aspects.

c. Develop the follow-on doctrine, materiel, organization and evaluation actions for Theater Army in accordance with the concepts and broad functions of the Theater Army developed by IAS [Institute of Advanced Studies].

d. Perform other combat developments actions as required.[5]

There are certain aspects of ICAS' missions and functions which must be understood at the outset of any discussion of the Institute's role in the development process. These aspects will be discussed in the following paragraphs.

As the specific tasks of ICAS are explored it should be remembered that a complete combat development cycle has never been completed in practice. As was indicated in Chapter IV, the development cycle embraces a 25 year time period (including the implementation phase).[6] Thus, sufficient time has not elapsed, during the six years of the Combat Developments Command's existence, for a combat developments cycle to run its course as is envisioned in the

---

[5]Institute of Combined Arms and Support, Organization, Mission and Functions Manual, USACDCICAS Regulation 10-1 (Fort Leavenworth, Kansas: 1967), p. 2.

[6]See Sequence of Materiel Development Actions, page 67.

current procedure manuals and management models. Therefore, much of the methodology which will be described is purely theoretical and will be put into practice for the first time in the development of the Army Combat Developments Program, Army-75. Presuming that the procedures followed are effective, it is reasonable to expect that such procedures will be in effect, perhaps with modification, during subsequent Army Combat Development Program periods. Thus, it will be assumed that the methodology to be described herein will be applicable to the Army-85 study of which the hypothetical CATAPULT system will be a part.

Although ICAS has the mission of developing materiel requirements,[7] the probability of the Institute ever doing so is quite remote.[8] Perhaps the idea for a new item of materiel may be suggested by ICAS in the combined arms and support doctrine study; however, the development of the materiel requirement in the form of a qualitative materiel development objective (QMDO) or a qualitative materiel requirement (QMR)[9] would be the responsibility of the respective branch or functional agency having proponency for the particular item of materiel.[10]

---

[7] See mission statement, subparagraph b., page 90.

[8] Interviews during April 1968 with LTC Lee C. Dickson, Materiel Branch, Literature-Organization-Materiel Division, ICAS; LTC Hans W. Strohm, Analysis and Operations Research Support Branch, Evaluation Division, ICAS; and LTC William B. Neal, Branch "A", Doctrine Studies Division, ICAS.

[9] See page 62 for definitions of these terms.

[10] A proponent organization is defined in USACDC Pamphlet 71-3, USACDC, Management Information System Procedural Guidance, p. 3, as: The USACDC organizational element which is assigned the primary responsibility for accomplishment of any combat development action.

In the case of the hypothetical CATAPULT missile system, the QMR would undoubtedly be developed by the USACDC Artillery Agency at Fort Sill under the direction of the USACDC Combat Arms Group.[11]

Organization

To discharge the responsibilities inherent in the aforementioned mission, ICAS is organized as shown in Figure 3.[12] A brief description of the missions and pertinent functions of the selected subordinate elements of ICAS is presented to provide the basis for the investigation of the application of Operations Research/Systems Analysis to the accomplishment of ICAS' mission.

Doctrine Studies Division

Doctrine Studies Division has the mission of developing studies for ICAS to include a doctrine study for each Army Combat Development Program.[13] This doctrine study is developed from a concept study and serves as the basis for basic derivative studies performed by the various branch and functional agencies within USACDC. The mission of this division will be discussed in greater detail in succeeding sections of this chapter; however, a brief explanation of this sequence of studies is in order at this time.

---

11 Interview with LTC Lee C. Dickson, Materiel Branch, Literature-Organization-Materiel Division, ICAS, 3 May 1968.

12 ICAS, Organization, Mission and Functions Manual, p. 1.

13 Ibid., p. 12.

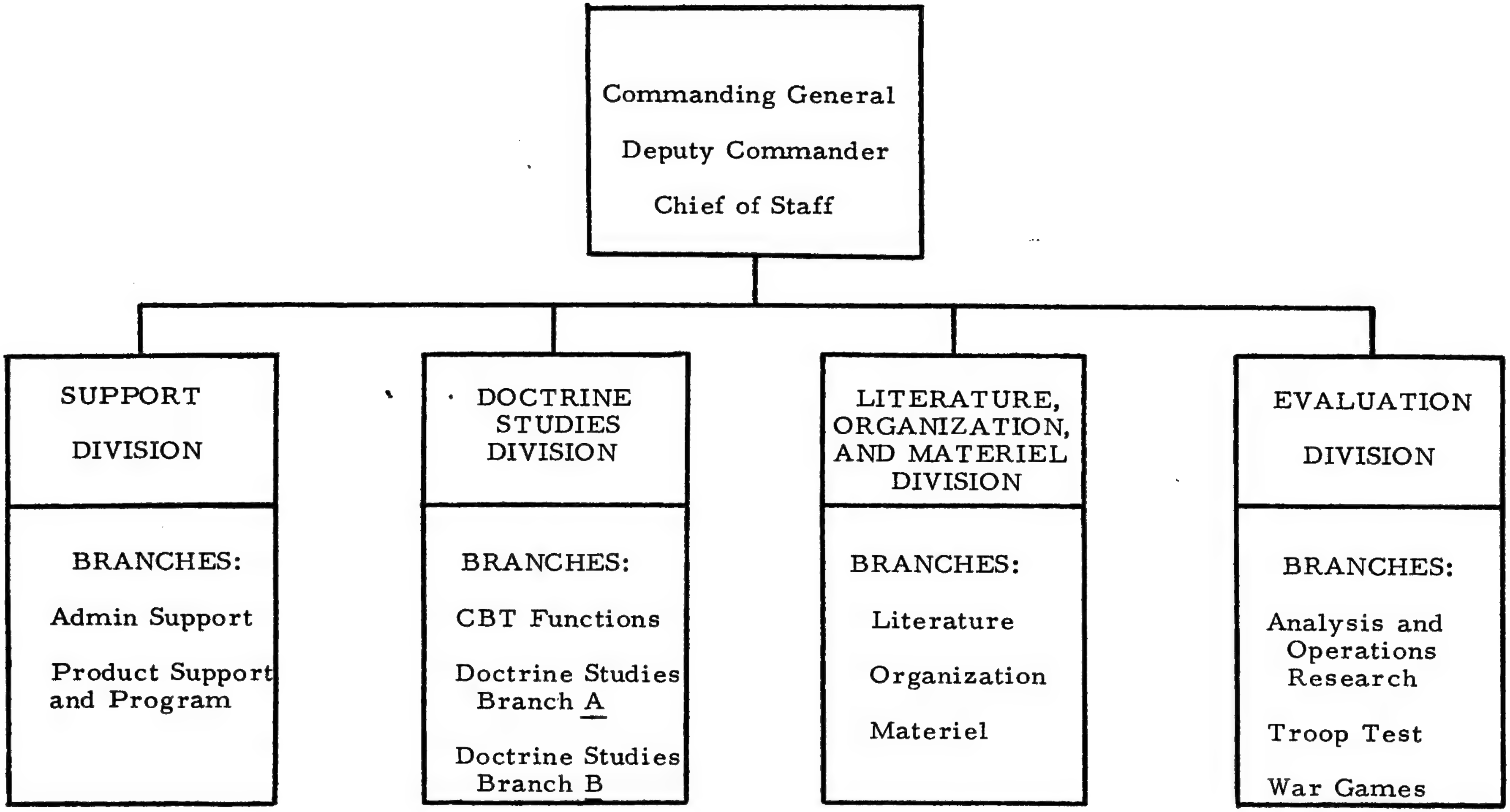

Figure 3. Organization Chart - Institute of Combined Arms and Support

Again, the development of the CATAPULT missile system will be used to describe a typical sequence of studies. "A concept study establishes the broad operational, materiel and organizational objectives for the doctrine phase of combat developments."[14] The concept study for 1980-85, Land Combat Systems Study (LCSS)-85, identified in general terms the materiel objectives in the fire power functional area that the Army would need during the time period under study. The doctrine study, Combined Arms and Support (CAAS)-85, narrowed these objectives and identified, in some detail, the requirement for a division support weapon system of the LANCE type for the 1980-85 time frame. The USACDC Artillery Agency in developing its basic derivative study (Artillery-85) gave greater definition to this identified need by describing the intended employment and operation of such a system in the Division Artillery family of the future.

The Doctrine Studies Division has a most important function to perform after the derivative studies have been completed. The derivative studies of the respective agencies (and those performed within ICAS) must be synthesized into the final product, the Army Combat Development Program, Army-85.[15]

---

[14] U.S. Army Combat Developments Command, USACDC Management Information System Procedural Guidance, USACDC Pam 71-3 (Fort Belvoir, Va.: 1968), Volume 1, p. 4.

[15] Informal analysis of the ICAS Master Model, Derivative Study Phase, ICAS File Number 201-45, p. 3., and interview with LTC William B. Neal, Branch "A", Doctrine Studies Division, ICAS, 3 May 1968.

Literature-Organization-Materiel Division

The Literature-Organization-Materiel Division has as its mission: "To develop . . . the follow-on doctrine, materiel, and organization requirements for divisions, corps, field army, army group, theater army, . . . in each Army Concept Program."[16] Through its Literature Branch, this division develops, and maintains current, the field manuals for which ICAS has proponency.[17] The Materiel Branch of this division is the focal point for information regarding the present state-of-the-art and technological forecasts. The Literature-Organization-Materiel Division is also responsible for the development of the tables of organization and equipment for the command levels previously identified in the ICAS mission statement.[18]

Evaluation Division

The Evaluation Division is responsible for validating; through the use of troop tests, war games, and other evaluation methodology; the doctrine, organization, and materiel requirements developed by ICAS.[19] In addition to these evaluation responsibilities, the Evaluation Division also has a support function as was mentioned briefly in the preceding chapter.[20] As the focal point of Operations Research/ Systems Analysis support within ICAS, the Analysis and Operations

---

[16] ICAS, Organization, Mission and Function Manual, p. 17.

[17] Ibid., pp. 17-18.

[18] Ibid., p. 17.

[19] Ibid., p. 22.

[20] See page 80.

Research Support Branch advises the other elements of ICAS on the employment of analytical techniques, provides a contracting officer's representative (COR) to monitor out-of-house operations research contractural support, and maintains a limited in-house operations research capability.[21]

ICAS Management Model

To understand the interrelationship of these various organizational elements in the accomplishment of the ICAS mission, it is essential that the ICAS management model be reviewed, since this model serves to guide the developmental process within the Institute. The critical management/decision check points which are amenable to the application of Operations Research/Systems Analysis will be isolated for further discussion in the next section of this chapter.

Phases in the ICAS Management Model

Since the ICAS management model was prepared without benefit of a USACDC model from which to be patterned,[22] slight variations in the designation of the phases of the development process can be noted. It is not necessary, however, that the ICAS phases coincide exactly with those identified by USACDC nor should the phases be forced into coincidence. At each level of employment, the management models should assist in the performance of the respective headquarters' mission and functions; thus, some disparity is to be expected.

---

[21] ICAS, Organization, Mission and Functions Manual, p. 23.

[22] Interviews with LTC Lee C. Dickson, Materiel Branch, during April 1968.

The phases depicted in the ICAS management model are as follows:

1. Concept Study Phase.

2. Doctrine Study Phase.

3. Derivative Study Phase.

4. Table of Organization and Equipment (TOE) and Field Manual (FM) Phase.

5. Implementation Phase.[23]

In the foregoing discussion of the mission and functions of the Doctrine Studies Division of ICAS, the end products (viz., the concept study, the doctrine study and the derivative study) of the first three phases were defined.[24] The TOE and FM phase serves to identify the organization, the manning levels and the skills required to support the approved operational directives[25] and to furnish the necessary literature to disseminate the approved doctrine to the users in the field. In the implementation phase there is a constant monitoring and evaluation of the entire developmental process. Feedback resulting from troop tests and other evaluation techniques provides the basis for updating of all of the phases of the developmental process and especially for the revision of TOE and FM's as required.[26]

---

[23] Informal Analysis of the ICAS Master Model, first 12 pages.

[24] See page 94.

[25] U.S., Department of the Army, Army Combat Developments, AR 71-1 (Washington: U.S. Government Printing Office, 1966), p. 5.

[26] Informal Analysis of the ICAS Master Model, Implementation Phase.

<u>Critical Management/Decision Check Points</u>

It has been noted in an earlier chapter that progress through the developmental cycle is dependent, to a great extent, upon the successful completion of certain key actions.[27] These actions may be viewed as critical check points if progress to the next step in the process is contingent upon a decision being rendered in the step in question. Thus, timely decisions based on accurate data and thorough analysis smooth the flow of the development process. In the following paragraphs specific key actions in the ICAS/CDC management models will be identified, isolated and discussed. The organizational element or elements within ICAS responsible for accomplishment of these actions will also be identified.

The detailed presentation of the part that modern analytical methods could play in facilitating the accomplishment of these critical actions will be withheld until the check points in each of the phases of the development process have been identified. Then the possible Operations Research/Systems Analysis applications to each action will be discussed in turn.

During the Concept Study Phase

USACDC's Institute of Land Combat is responsible for the development of the Land Combat Systems Study (concept study).[28]

---

[27]See Chapter IV, page 84.

[28]U.S. Combat Developments Command, <u>Organization, Mission and Function</u>, USACDC Pamphlet 10-1, p. 12-1.

As described earlier, this study is quite general and broad in nature. It has been suggested, informally, that in order for ICAS to influence the Army of the future as early as possible that ICAS should provide input to the Institute of Land Combat (ILC) for the concept study.[29] War gaming by the Evaluation Division of ICAS could perhaps provide the necessary quantitative data for such input. In the opinion of the author, ICAS should withhold comment until after ILC has prepared a Draft Land Combat Systems Study at which time the concept will be more clearly defined and will be more easily analyzed by the Doctrine Studies Division with advice and assistance, as necessary, being provided by the Evaluation Division.[30]

There is within the concept study phase an action for which ICAS is responsible which may provide fertile ground for the application of Operations Research/Systems Analysis technique. This action is the review and analysis of alternative conceptual designs which are set forth by ILC in the draft concept study. The approval of the concept study signals the beginning of the transition into the Doctrine Studies Phase.[31]

---

[29]Informal Analysis of the ICAS Master Model, Concept Study Phase, p. 1.

[30]This opinion was developed through extensive discussion with action offices within ICAS to include, LTC Lee C. Dickson, LTC William B. Neal, et. al.

[31]USACDC Institute of Combined Arms and Support, ICAS Master Model, unpublished, copy available in Materiel Branch files, Literature-Organization-Materiel Division.

During the Doctrine Studies Phase

With the approval of the concept study, ICAS begins work on the combined arms and support study (doctrine study).[32] Of course, combined arms doctrine is the primary product of the Institute of Combined Arms and Support.[33] The first action in the doctrine studies phase of significance to this discussion occurs when the Doctrine Studies Division of ICAS prepares requests for input upon which to base its doctrine study. Herein, other CDC agencies, major commands and contractor input are defined and doctrinal alternatives are developed. This action provides for possible application of Operations Research/Systems Analysis in the conduct of the first of a series of study progress reviews (SPR). This review is essentially what is referred to elsewhere in the developmental process as an in-process review (IPR).[34] A study progress review involves a review by agencies representing both ICAS and out-of-house interests.

When the inputs which were requested are received they must be analyzed and the best doctrinal approach selected by the Doctrine Studies Division. These data include materiel requirements (QMDO's and QMR's) received from agencies and groups within USACDC which

---

[32]Informal Analysis of ICAS Master Model, detailed analysis of Doctrine Study Phase.

[33]See ICAS mission, p. 88.

[34]Interview with LTC Lee C. Dickson, Materiel Branch, ICAS, April 1968.

must be reviewed by the Materiel Branch of the Literature-Organization-Materiel Division. Finally, in the doctrine study phase, before the doctrine study can be approved, comments on the coordination draft must be incorporated into the study by means of another study progress review.

Clearly, these actions are not the only actions which need to be accomplished during the doctrine phase. They do, however, represent the actions which are the most likely candidates for the application of Operations Research/Systems Analysis techniques and will be discussed in that light subsequently. Although a line drawn on a chart after Department of the Army approval of the doctrine study marks the beginning of the derivative study phase; in practice, the interface between these two phases is not nearly so clear. Because of interagency coordination, basic derivative studies are often begun before or concurrent with the approval of the doctrine study.[35]

During the Derivative Study Phase

The branch and functional agencies subordinate to the USACDC Groups have primary responsibility for the development of derivative studies. ICAS may conduct derivative studies within its assigned proponency and when doing so is directed by Headquarters, USACDC. ICAS furnishes doctrinal guidance to the agencies which are developing the basic derivative studies.[36]

---

[35]Informal Analysis of ICAS Master Model, Doctrine Study Phase, p. 2.

[36]Interview with LTC Lee C. Dickson, Materiel Branch, ICAS, April 1968.

The important management check point in this phase comes after the branch and functional agencies have completed their basic derivative studies. As was stated earlier, the Doctrine Studies Division, ICAS, has the responsibility of analyzing and synthesizing those derivative studies (plus any that had been developed within ICAS) and producing therefrom the completed Army Combat Development Program (e.g. Army-85). This analysis and synthesis is an undertaking of sizeable proportions and can benefit greatly from the application of modern analytical techniques. It is presently envisioned that there will be "sub-synthesis" at the USACDC Group level of the derivative studies for which the group has proponency. This technique should facilitate the final synthesis by ICAS and accelerate the developmental process.[37]

During the TOE and FM Phase

In this phase, the documents necessary to promulgate the approved Army Combat Development Program to the field are developed. Primary responsibility is vested in the Literature and Organization Branches of the Literature-Organization-Materiel Division.[38] The Materiel Branch monitors the materiel development which is going on concurrently. The Doctrine Studies Division monitors the effort to insure the integration of approved doctrine into these guidance documents. The responsibilities are the same whether the action

---

[37]Interview with LTC William B. Neal, Doctrine Studies Division, ICAS, 3 May 1968.

[38]See page 95.

produces an entirely new TOE or FM or if it merely results in a change or a revision to existing documentation. The actions taken in this phase are coordinated primarily through the use of internal reviews[39] and are not considered critical in the same sense as those management actions described in connection with the earlier phases of the developmental process. Classical management methods are usually sufficient to insure the successful completion of the TOE and FM phase. However, modern management methods (particularly war gaming) can often assist in providing data for validation of new or revised doctrine. This application will be discussed further in the following section of this chapter.

During the Implementation Phase

During this phase, the Literature-Organization-Materiel Division maintains a vigilance to insure that proponent TOE and FM's accurately reflect approved Army doctrine. The remarks made with regard to criticality and management techniques in the preceding paragraph apply to the activities of the implementation phase as well and will not be reiterated here.

ICAS Management Model: Impressions and Summary

As the development process is being pursued by the elements of ICAS, similar actions are being performed concurrently by the USDA

[39] Internal reviews differ from study progress reviews and in-process reviews in that they are conducted within the ICAS organizational framework for the purpose of obtaining a consolidated position prior to forwarding any action to headquarters or agencies outside of ICAS.

and the USACDC on the management check points within the framework of their respective management models. Attention of these commands is focused on such decision and analysis actions as trade-off evaluations, cost/effectiveness analyses, engineering feasibility determinations, etc., as summarized at the end of Chapter IV.

The ICAS management model, despite certain variations in terminology, is compatible with the development process described in the Department of the Army and U.S. Army Combat Developments Command management models. Further, the ICAS model supports the overall objective of materiel development management as set forth in FM 38-7.

> The objective of materiel development is to develop materiel which achieves stated performance requirements within stated time schedules at minimum cost for development, production, and operation.[40]

In the following section of this chapter the applicability of Operations Research/Systems Analysis techniques to the critical management/decision points identified in the ICAS management model will be investigated. The actions against which the application of the modern analytical methods is to be investigated are summarized briefly below:

1. Review and Analysis of Alternative Conceptual Designs.

2. Requests for Input to Doctrine Study - Study Progress Review.

3. Analysis and Selection of Best Doctrinal Approach.

---

[40]U. S., Department of the Army, Logistics, Materiel Development Management, FM 38-7 (Washington: U.S. Government Printing Office, 1966), p. 2-4.

4. Comments on Coordination Draft - Study Progress Review.

5. Analysis and Synthesis of Derivative Studies.

Operations Research/Systems Analysis

General

With the explanation of the role of ICAS in the development of the Army Combat Development Program as background, the remainder of this chapter will be devoted to an investigation of the application of modern analytical methods[41] to the previously identified management actions in the developmental process. The materiel will be organized as follows. Each action will be taken in turn and, depending upon the nature of the action, a technique (or techniques) will be suggested which if employed will facilitate, improve or optimize decision-making at these critical points. Should there be more than one technique which might have application to the action step being investigated the relative suitability of such techniques for that particular application will be identified. Following this detailed discussion, some remarks will be made regarding the possible general applications of Operations Research/Systems Analysis to ICAS methodology. Finally a policy for the incorporation of the suggestions made herein to the ICAS managemenet model will be proffered.

---

[41]See Chapter III for a discussion of some representative Operations Research/Systems Analysis techniques.

Review and Analysis of Alternative Conceptual Designs

To understand the nature of these alternative conceptual designs it should be realized that the Institute of Land Combat (ILC) prepares these broad guidelines from input furnished from varied sources such as: technological forecasts, threat (conflict situation) studies, projections of national and allied policies, etc. Thus, it can be seen that the alternative concepts are necessarily replete with parameters which are neither purely quantitative nor amenable to direct application of mathematical analysis. Nonetheless, ICAS has the responsibility of analyzing these alternatives for further development.[42] Such problems are best approached by probabilistic means. As was noted earlier, probability theory is particularly useful in coping with abstract and often ill defined parameters.[43] This theory can be applied through the construction of a probabilistic model, which by its nature must be quite abstract. Since these models are abstract, are they useless as analytical tools? Quite the contrary is true. They are "made to order" for performing the type of analysis that ICAS must perform in the early portion of the combat development cycle, i.e., in the concept study phase. The utility of such abstract modelling is noted by Martin and Starr as they compare concrete and abstract

---

[42]Informal Analysis of ICAS Master Model, detailed analysis of Concept Study Phase.

[43]See discussion of probability theory, Chapter III, page 34.

modelling in their recent book, Executive Decisions and Operations Research.

> Generally speaking - and it is not possible to be specific - concrete models have advantages over abstract models for purposes of communication and observation. Abstract models have greater flexibility for both analysis and manipulation. Concrete models are closer to facts while abstract models are nearer to laws and general principles which can be applied over and over again. It is quite clear that these thoughts tie in with the decision-maker's difficulty in handling great numbers of strategies and states of nature.[44]

The dilemma of the decision-maker alluded to here is not unlike that of ICAS in its attempt to reduce a great number of elusive variables to manageable proportions and to select the best alternative concept design from the array which has been presented by the Institute of Land Combat.

Included in this action step for ICAS, though not specifically identified earlier, is the requirement to review draft operational capability objectives (OCO). This review can be easily integrated into the aforementioned analysis as the materiel aspects of the concept of the Army of the future will, if properly conceived, support the concept which is being formulated and should be a part of the overall review and analysis.

Thus, the probabilistic approach with its implied simulation (in the form of an abstract model) presents itself as the best technique to employ in the performance of the review and analysis of alternative conceptual designs. War gaming could possibly have application in

---

[44]David W. Miller and Martin K. Starr, Executive Decisions and Operations Research, (Englewood Cliffs, New Jersey: Prentice-Hall, Inc., 1960), pp. 116-117.

this analysis; however, this technique will provide greater assistance to the decision maker if withheld until the parameters involved can be more definitely stated.[45] It should come as no surprise to the reader that as the development process brings ICAS closer to the implementation phase, the Operations Research/Systems Analysis techniques suggested for employment will be shifting from those which are predominantly "probabilistic" in character to those which are essentially "deterministic."

In the actual application of these techniques within ICAS, it is suggested that the Doctrine Studies Division have primary responsibility for the conduct of the review and analysis of the alternative conceptual designs as is presently envisioned.[46] Input data relating to the materiel aspects of the review would, of necessity, be provided by the Materiel Branch of the Literature-Organization-Materiel Division. If this analysis is conducted using an abstract probabilistic model, as has been suggested, greater reliance will have to be placed on the analytical talents (both in-house and contract) of the Analysis and Operations Research Support Branch than is presently envisioned. A suggested staffing pattern for this branch will be presented in a subsequent paragraph of this section.

---

[45] E. S. Quade (ed.), Analysis for Military Decisions, R-387-PR (Santa Monica, Calif.: The Rand Corporation, 1964), p. 219.

[46] Interview with MAJ Pierce T. Seago, Jr., Doctrine Studies Division, 16 May 1968.

Requests for Input - Study Progress Review

One might question the selection of this action as a key management point in the accomplishment of the ICAS mission. A slight digression to explain the logic behind this selection will be undertaken. It has been stated earlier that the doctrine study is the primary product which the Army derives from the efforts of ICAS. The data which are being requested as input in this phase will serve as the raw materiel from which the finished product will be fabricated. One would not want to receive deficient input data in a study development process any more than he would want to receive adulterated milk into an ice cream factory. Or couched in the phraseology of the analyst: "After all if we are unclear about what it is we are really seeking, no advances in analytical technique are going to help us very much."[47] or "To get a neat answer to the wrong question may be worse than getting an incomplete answer to the right question."[48]

With the importance of appropriate input data established, the discussion may proceed to an investigation of the techniques which if employed should produce the desired results. This action is identified with a study progress review (SPR) and the relationship between the application of Operations Research/Systems Analysis techniques and this review will also be explored.

The two important tasks to be performed in the accomplishment of this important step were identified previously as the definition of

---

[47]J. R. Goldstein, Scientific Aids to Decision Making, P1042 (santa Monica, Calif.: The Rand Corporation, 1957), p. 7.

[48]Ibid., p. 3.

input and the development of doctrinal alternatives. Herein, the task of ICAS is quite different from that which confronted the Institute of Land Combat (ILC) in the preparation of the concept study. ILC proceeded from a rather nebulous aggregation of source documents (e.g. the Basic Army Strategic Estimates, the Army Strategic Plan, etc.); thus, the methodology employed had to be able to cope with essentially abstract input data. ICAS, on the other hand, proceeds from a somewhat concrete concept study in the development of its doctrine study; thus, the techniques employed can be those which possess a capability to convert fairly definitive input data into a series of alternative doctrinal approaches.

First, to identify the input data which will be required a type of "reverse war gaming" might be employed.[49] From the basic concept study perform a war game which through a manipulation of gaming parameters will yield a series of possible alternative doctrinal approaches to satisfy the concept. This approach differs from the conventional war game approach in that alternative solutions are being sought rather than an optimum solution. In a conventional war game application the players are constrained by clearly defined rules of play and a known payoff. When the payoff is known, and the players are assumed to be logical and rational, there is complete knowledge on both sides as to the factors that motivate the opponent. In the approach described above the payoff is not known and, in fact,

---

[49] The term "reverse war gaming" was coined by the author to describe a methodology which the author deduced from a discussion of war gaming by M. G. Weiner in Analysis for Military Decisions, pp. 217-226 (see note 45), and other sources.

the payoffs achieved through variation of the rules to play and other parameters are the alternative doctrinal approaches. With these doctrinal alternatives in view, clearer input requirements can be identified. It can be seen that this "reverse war gaming" yields a valuable by-product in that an entire family of possible alternative doctrinal approaches is produced which serves as a basis for comparison of the respective approaches and the selection of the one which best satisfies the concept study.

The Doctrine Studies Division should exercise primary responsibility over the conduct of this phase of the developmental process, coordinating the activities of the other in-house branches and divisions. The War Games Branch of the Evaluation Division would be required to provide the war game facility for the conduct of the "reverse war game" process described above. Close coordination between the War Games Branch and the Analysis and Operations Research Support Branch during this action would be required because the facility is being used for essentially an analysis function as opposed to its normal employment in support of ICAS' evaluation role. During the TOE and FM phase and the implementation phase the war game facility would be used extensively to validate new or revised doctrine in cases where troop testing was not feasible or desirable.[50]

Analysis and Selection of Best Doctrinal Approach

After the inputs to the Doctrine Study are received from both in and out-of-house participants, the data must be incorporated into

[50]Interview with LTC Hans W. Strohm, Evaluation Division, ICAS, 3 May 1968.

the doctrine studies. After analysis and incorporation of these many inputs, a coordination draft doctrine study is circulated to interested agencies for comment and/or concurrence.[51] It goes without saying, as before, that the materiel requirements are a part of this overall analysis and thereby a clearer definition of the future military hardware is becoming possible.

The suggested methodology to accomplish this step in the developmental process is one of conventional war gaming as described above. With the respective inputs as the variable parameters war game successively the various doctrinal approaches to identify the optimum doctrine approach. The parameters at this point are more clearly defined than at any prior point in the developmental process but are still not sufficiently definitive to subject the alternative doctrine study to the rigors of analysis by linear or dynamic programming techniques.

There would be no need for realignment of functions for the accomplishment of this management action in that the Doctrine Studies Division would retain overall responsibility, assisted by the Materiel Branch and the War Games Branch as required. The coordination draft doctrine study which results from the analysis and selection process discussed above is the vehicle for the accomplishment of the next significant management action (i.e. coordination of the draft doctrine study).

---

[51]Informal Analysis of ICAS Master Model, detailed analysis of Doctrine Study Phase.

Comments on the Coordination Draft - Study Progress Review

Before the Doctrine Study (e.g. CAAS-85) is released for approval it is made available to all interested parties (both within ICAS and out-of-house) for comment.[52] As indicated in the descriptive title of this action, a study progress review is the device used to afford all interested agencies the opportunity to take "one last look" at the doctrine study before it is submitted to Department of the Army for approval. The study progress review will be discussed separately below.

The suggested methodology for obtaining the final coordination of the draft doctrine study is a combination of classical project officer techniques and limited Operations Research/Systems Analysis application. The project officers who are responsible for the various "pieces" which fit into the completed doctrine study, exercising their personal expertise in reviewing the draft study, make recommendations and provide suggested changes to the coordinating agency during the study progress review.

Until the draft doctrine study is released for approval, the Doctrine Studies Branch is responsible for obtaining the requisite concurrences and incorporating any changes needed to make the doctrine study acceptable to the participants in the study progress review.[53] The Analysis and Operations Research Support Branch

---

[52] Ibid.

[53] Interview with MAJ Homer B. Moran, Doctrine Studies Division, ICAS, May 1968.

provides the limited Operations Research support in the form of parametric studies and analysis.

Study Progress Review

Two of the last three management actions were performed in conjunction with Study Progress Reviews (SPR). It is appropriate at this point to consider the contribution which Operations Research/ Systems Analysis can make to the expeditious accomplishment of these reviews. It should be remembered that these reviews are attended by all agencies both in and out of ICAS which have an interest in the forthcoming doctrine study. Often, the needs of any one agency cannot be completely satisfied without compromising, or at worst sacrificing, the needs or expressed desires of some other organizational element. Herein lies one of the stickiest of management's decision problems. Operations Research/Systems Analysis can, if properly employed, provide quantitative and rational considerations upon which to base a decision. For those points of contention which can be resolved by rigorous analytical methods and which do not involve subjective judgment, the assistance which can be rendered by the application of quantitative management techniques can be considerable. The subjective arguments will still require solution; however, the total time required to reach agreement should be reduced perceptibly. The Analysis and Operations Research Support Branch should be able to provide all the assistance required during the study progress reviews either through in-house capability or through contractor support. The expenditure of contractor effort on projects of this nature (which may be construed to be a personal service

contract) will be discussed in detail in the next section of this chapter.

Analysis and Synthesis of Derivative Studies

The final management/decision check point to be investigated is that of the analysis and synthesis of the derivative studies of the various proponent agencies into a homogeneous Army Combat Development Program for the appropriate time period. This action is one of the more demanding of the management efforts undertaken by ICAS during the developmental process.[54] Fortunately, however, this point is not reached by ICAS in a vacuum in that numerous in-process reviews have preceded this final coordination action before the development moves into the TOE and FM Phase.

Briefly, at this check point all of the derivative studies (sub-synthesized at the group levels as was mentioned earlier)[55] are synthesized into the final Army Combat Development Program. Herein the variables are clearly enough defined that they are amenable to flow charting techniques, program evaluation and review techniques (PERT) and even, to a limited degree, the advanced techniques of linear and dynamic programming and more elaborate simulations requiring mathematical models and extensive automatic data processing support. To successfully pass this important check point will require the concerted efforts of almost every element of the Institute of Combined Arms and Support. Once again the action will be guided by the

[54]Interviews with LTC William B. Neal, Doctrine Studies Division, and LTC Hans W. Strohm, Evaluation Division, ICAS, May 1968.

[55]See page 102.

Doctrine Studies Division with the Materiel Branch reviewing the QMDO's and QMR's. The Literature and Organization Branches will be attuned to the implications in their respective areas of interest of any changes brought about by the amalgamation of the various studies into the completed Army Combat Development Program.

It is envisioned that the Evaluation Division will be employed in a unique manner during this phase of the development. To glean the maximum benefit from the analytical talents of the Operations Research/ Systems Analysis Specialists (military, DA civilian, and contractor) they will be assigned to work within the Doctrine Support Division during the synthesis so that there will be a maximum interchange of ideas between the men possessing mature military judgment and the men who possess the invaluable analytical skills of the sciences.

The suggestion to employ a contractor in the manner described above presents an exceptional problem. It is believed by many action officers that a side-by-side working relationship with the operations research contractor would result in the most efficient utilization of the contractor's capability.[56] However, such professional assistance, if interpreted to be a personal service, is expressly prohibited by regulation.[57] That fact notwithstanding, the author still suggests that every effort be made to effect such an arrangement, if the military and in-house civilian capability is not sufficient to provide

---

[56]Interviews with LTC William B. Neal, MAJ Pierce T. Seago, Jr., *et. al.*, ICAS, May 1968.

[57]U.S. Army Combat Developments Command, *Contractual Scientific Support*, USACDC Regulation 71-6, (Ft Belvoir, Va.: 1966), paragraph 4, p. 2.

adequate operations research support.

General Application of Operations Research/ Systems Analysis Within ICAS

There are two additional areas which are likely candidates for the application of Operations Research/Systems Analysis techniques which could not be appropriately identified under any of the previous subdivisions and they will be discussed at this time.

The Interdisciplinary Team

At the time of this writing (1968) the only in-house Operations Research/Systems Analysis capability possessed by ICAS is in the person of the military Branch Chief of the Analysis and Operations Research Support Branch.[58] Obviously he can do little more than monitor the out-of-house operations research contracts and advise the other ICAS elements on ways to employ the technical contractor support. It is suggested that as the authorized civilian spaces within the Analysis and Operations Research Support Branch are filled that they be filled with persons with sufficient background to form an interdisciplinary team. Persons with training in business, the physical sciences, automatic data processing, and mathematics should make up this branch when it has its full complement of personnel.

Internal Reviews

As was described earlier, internal reviews differ from in-process reviews and study progress reviews in the scope of coverage

---

[58] Interview with LTC Hans W. Strohm, Chief of Analysis and Operations Research Support Branch, Evaluation Division, ICAS, April 1968.

only.[59] The discussion regarding the benefits that would accrue from the use of Operations Research/Systems Analysis findings as the basis for study progress reviews is equally applicable to internal reviews.[60] If applied, these modern management methods will facilitate the in-house staffing of combat development actions within ICAS.

Suggested Policy

The suggested policy for incorporating Operations Research/ Systems Analysis into the ICAS management model is set forth as an appendix in the form of a draft ICAS Bulletin. Bulletins such as these are used to promulgate official policy and guidance to personnel within ICAS.

Summary

This chapter represented a synthesis of the Operations Research/ Systems Analysis techniques of Chapter III and the combat development process presented in Chapter IV. The Institute of Combined Arms and Support (ICAS) management model was explored in detail and management actions therein which were suitable for the application of Operations Research/Systems Analysis techniques were identified as follows:

1. Review and Analysis of Alternative Conceptual Designs.
2. Request for Input to Doctrine Study.
3. Analysis and Selection of Best Doctrinal Approach.
4. Comments on Coordination Draft - Study Progress Review.

---

[59] See note 39, this chapter.

[60] See page 114.

5. Analysis and Synthesis of Derivative Studies.

The techniques which were suggested for employment in these respective action areas ranged from the application of probability theory during the Concept Study Phase of development, through war game applications early in the Doctrine Study Phase, to the application of linear and dynamic programming in the final stages of the Derivative Study Phase. This progression is possible because of the fact that the data which are being considered become more clearly defined and more quantitative as the development approaches the implementation phase.

Finally, these suggestions were codified into a policy for incorporating Operations Research/Systems Analysis into the ICAS management model. Adoption of the suggested policy would materially enhance the Institute of Combined Arms and Support's ability to apply modern analytical methods in the accomplishment of its combat development mission.

CHAPTER VI

EPILOGUE

Introduction

This chapter will be devoted to the expression of some general impressions of the author regarding future applications of Operations Research/Systems Analysis techniques to the entire combat development process as a single system. The impressions are necessarily those of a student of scientific management and not of an expert in the field.

To define an Army Combat Development Program for a specific time period from its inception to its implementation, and further to attempt to define its many variables in terms which are sufficiently quantitative to permit mathematical manipulation would certainly represent an ambitious undertaking. Even the most loyal supporters of modern analytical techniques might justifiably raise a double-barreled question at this point. Is it possible to construct a model which accurately represents a system which is so complex; and, if the answer be yes, what is to be gained by doing so? These questions will be addressed in turn in the following paragraphs.

Feasibility

First, is the construction of a model of the entire Army Combat Development Program possible? The answer to that question is one of those unknown quantities with which Army Combat Development

personnel will have to grapple for some time to come. It is expected that there will continue to be suboptimization of the parts which make up the overall program as there has been in the recent past (e.g., the development of individual weapon systems like the POLARIS and SENTINEL Systems[1]) with a subsequent incorporation of the optimized parts into the "optimum" whole. Although this approach seems quite logical there is an inherent danger in it which is well known in classical economics as the "fallacy of composition" which in the present context could introduce such specious reasoning as follows: That which is best for the individual branches or functions will also be best for the whole army which is produced from the combination thereof. The fallacy is even clearer in the example from economics offered by Abbott: "Some people make enough by stealing to live in luxury. Therefore, if everybody stopped working and stole from each other, everybody could live in luxury!"[2] To overcome this shortcoming a systems view must be taken which encompasses the largest feasible combination of variables. Churchman expresses the goal of operations

---

[1]Modern analytical methods have been used successfully in the development of both systems. For an interesting discussion of the application of Probabilistic and Monte Carlo techniques to the problem of selecting sites for the SENTINEL missile system see James P. Dix, "Game-theoretic Applications," IEEE Spectrum, Volume 5, Number 4, April 1968, published by the Institute of Electrical and Electronic Engineers, Inc., pp. 108-117.

[2]Lawrence Abbott, Economics and the Modern World (New York and Burlingame: Harcourt, Brace and Company, 1960), p. 623.

research in this regard as follows. "O. R. [Operations Research] tries to find the best decisions relative to as large a portion of the total organization as possible."[3] In the context of the present discussion the system to be defined would be the Army Combat Development Program for a particular 5 years implementation period.

Advantages

Regarding the advantages which may attend such a systems approach to combat developments the prospects are promising enough to warrant attention. Some of the possible advantages will be discussed briefly at this time.

The first advantage accrues from the fact that mathematical models can be adjusted to changing variables readily; whereas, it is extremely difficult and expensive to make changes in a real world system after the ideas have been converted into the "nuts and bolts" of military hardware. This advantage is summarized aptly by Optner when he writes:

> Through the techniques of operations research, it is possible to examine the validity of the basic premises under which the system may be organized prior to any physical commitment of labor, materiel or capital.[4]

Further, the systems approach gives the military planner a greater assurance that all of the factors which will influence the success of future military operations are considered in the development program.

---

[3] C. West Churchman, et. al., Introduction to Operations Research (New York: John Wiley and Sons, Inc., 1957), p. 6.

[4] Stanford L. Optner, Systems Analysis for Business Management (Englewood Cliffs, N.J.: Prentice Hall, Inc., 1960), p. 158.

The analysis which is integral to Operations Research/Systems Analysis methodology stimulates the imagination and sharpens the intuition of the military planner and should provide for a more comprehensive army structure for the future.

Trade off analyses among the components of the complex systems has always been a difficult management problem. If an overall systems approach is adopted many of these trade off problems resolve themselves in that there is an automatic resolution of conflicting interests which may exist among the component elements in deference to the identified needs of the larger system.

Conclusions

Despite the apparent advantages that could be derived from a greater application of Operations Research/Systems Analysis to the combat development process, there still exist many practical and cogent arguments which tend to discourage extensive application of these techniques. Some of these arguments are discussed below.

The age-old proverb that "All that glitters is not gold" is applicable to the employment of modern analytical techniques. Many managers place inordinate reliance upon the findings of the operations researcher or systems analyst without critically analyzing these findings merely because these specialists are the proponents of the modern and highly scientific management techniques. The techniques of Operations Research/Systems Analysis will never antiquate the need for executive decisions which are based in part on experience and

intuition. These techniques, however, are valuable supplements to the exercise of professional judgment by the manager. In the opinion of the author, the key to successful modern management, be it in business or in the military, is in finding the balance between the purely analytical and the purely intuitive approaches to decision-making, not overlooking the valuable asset which is available in the techniques of Operations Research and Systems Analysis.

APPENDIX

DRAFT

ICAS BULLETIN

US ARMY COMBAT DEVELOPMENTS COMMAND
INSTITUTE OF COMBINED ARMS AND SUPPORT
FORT LEAVENWORTH, KANSAS 66027

PUBLISHED TO PROVIDE OFFICIAL POLICY AND GUIDANCE
TO ICAS PERSONNEL

Issue No. ______ ______________, 19 __

OPERATIONS RESEARCH/SYSTEMS ANALYSIS #1

1. GENERAL.

a. The opportunity to apply scientific management in the performance of ICAS' combat development mission is not being exploited to the maximum extent possible. This bulletin has been prepared to assist ICAS personnel in taking full advantage of the modern analytical methods available to them.

b. As studies in support of the Army Combat Development Program progress through the various developmental phases within ICAS, the Doctrinal Studies Division maintains overall responsibility for assuring that appropriate actions are taken and that schedules are met in the accomplishment of ICAS' mission. A project officer within the Doctrine Studies Division will be designated to monitor the progress of each study.

c. In all phases of the development of the Combat Development Program, and especially in the Doctrine Study Phase, the facilities and talents of the Evaluation Division should be utilized to a greater extent than has been done heretofore. Personnel of the division must be contacted as early in the developmental cycle as possible for suggestions as to the methods and procedures to be employed in introducing quantitative analysis where possible and appropriate. The Analysis and Operations Research Support Branch through the in-house expertise which it possesses can engage in limited operations research projects itself in support of study programs and is the focal point within ICAS for all contractual operations research support. Thus,

coordination with the Analysis and Operations Research Support Branch at the earliest practicable date is essential if contract operations research support is contemplated. The War Games Branch provides the facility and the methodology for the application of gaming techniques to the analysis and review of studies within ICAS.

2. INCORPORATION OF OPERATION RESEARCH/SYSTEMS ANALYSIS INTO THE ICAS MASTER MODEL.

Within the ICAS Master Model there are various management/decision check points the passing of which can be facilitated by the application of Operations Research/Systems Analysis techniques. In the following paragraphs some of the more important decision check points will be identified and a brief description of the types of operations research/systems analysis methodology which could be employed will be given. The decision check points which will be discussed are as follows:

(1) Review and Analysis of Alternative Conceptual Design.

(2) Requests for Input to Doctrine Study.

(3) Analysis and Selection of Best Doctrinal Approach.

(4) Comments on Coordination Draft.

(5) Analysis and Synthesis of Derivative Studies.

3. REVIEW AND ANALYSIS OF ALTERNATIVE CONCEPTUAL DESIGNS.

In this action, the alternative conceptual designs provided to ICAS by the Institute of Land Combat (ILC) must be reviewed and analyzed and ICAS must select the concept which seems to best satisfy the requirements of the Army in the future from ICAS' point of view. Herein, the Operations Research Support Branch can provide for application of probability theory through the construction of a probabilistic model against which the alternative conceptual designs may be tested.

4. REQUESTS FOR INPUT TO DOCTRINE STUDY.

At this management check point, ICAS requests input from various interested agencies to serve as the basis for the doctrine study [Combined Arms and Support (CAAS) __]. Operations Research/Systems Analysis techniques can be very valuable at this juncture in assuring that input requested is that which is needed for subsequent development of the study. The War Games Branch will assist through the application of war gaming techniques in identifying the important input parameters. This activity will provide a valuable base for the decision which will have to be made by ICAS in the selection of the best doctrinal approach.

5. ANALYSIS AND SELECTION OF BEST DOCTRINAL APPROACH.

With the inputs having been received, ICAS must analyze these data and select the approach which is felt provides the best doctrine to guide the army of the future. The war gaming work which had been accomplished in previously described management check points will serve as the basis for "war gaming" each of the doctrinal approaches to select the one which best satisfies the concept of the army in the time frame in question.

6. COMMENTS ON COORDINATION DRAFT.

Before the doctrine study is released from ICAS for approval by CDC and Department of the Army a coordination draft must be circulated and comments solicited from all interested agencies. The incorporation of these comments into a final draft must be accomplished by ICAS and again Doctrine Studies Division has the responsibility of accomplishing this coordination. Although classical project office coordination techniques will be the primary means of performing this action, operations research support provided by the Analysis and Operations Research Support Branch can provide a quantitative base for resolving differences of opinion among the contributing agencies.

7. ANALYSIS AND SYNTHESIS OF DERIVATIVE STUDIES.

After the doctrine study is approved, the CDC agencies submit their derivative studies through their respective groups to ICAS for synthesis into the final Army Combat Development Program (Army __). At this step the operations research capability of ICAS must be exploited to the maximum extent possible. Both in-house and contractor effort must be expended to support the project officer in his analysis and synthesis of the derivative studies. Techniques to be employed will include: flow charting, program evaluation and review techniques (PERT), trade-off analyses and to the extent possible the more rigorous techniques of linear and dynamic programming and elaborate simulations requiring extensive automatic data processing support.

8. CONCLUSION.

An awareness of the Operations Research/Systems Analysis capability possessed by ICAS and its full utilization will assist ICAS in producing the best possible Combat Development Program Study for the Army of the future.

9. REFERENCES:

a. AR 71-1, Army Combat Developments.

b. USACDC Regulation 71-1, Combat Developments Procedures.

c. USACDC Regulation 17-6, Contractual Scientific Support.

d. USACDC Regulation 17-16, Monitorship of Contractual Scientific Support.

e. Methodology Notebook for Action Officers.

f. USACDCICAS Regulation 10-1, Organization, Mission and Functions Manual.

g. USACDCICAS 71-1, Utilization of the Institute of Combined Arms and Support Research Office.

FOR THE COMMANDER:

BIBLIOGRAPHY

BIBLIOGRAPHY

Public Documents

U.S. Department of the Army. Reorganization of the Office, Chief of Staff, Chief of Staff Memorandum 67-64. Washington: Department of the Army, 16 February 1967.

U.S. Department of the Army. Contracting for Management, Operations Research and Automatic Data Processing Services, Studies and Projects, AR 1-110. Washington: U.S. Government Printing Office, January 1968.

U.S. Department of the Army. United States Army Materiel Command, AR 10-11. Washington: U.S. Government Printing Office, March 1965.

U.S. Department of the Army. United States Army Combat Developments Command, AR 10-12. Washington: U.S. Government Printing Office, June 1965.

U.S. Department of the Army. The Management Process for Development of Army Systems, AR 11-25. Washington: U.S. Government Printing Office, April 1968.

U.S. Department of the Army. System/Project Management, AR 70-17. Washington: U.S. Government Printing Office, January 1968.

U.S. Department of the Army. Operations Research Projects and Studies Conducted by Research Analysis Corporation, AR 70-20. Washington: U.S. Government Printing Office, August 1962.

U.S. Department of the Army. Army Combat Developments, AR 71-1. Washington: U.S. Government Printing Office, May 1966.

U.S. Department of the Army. Dictionary of United States Army Terms, AR 320-5. Washington: U.S. Government Printing Office, April 1965.

U.S. Department of the Army. Army Research and Development, AR 705-5. Washington: U.S. Government Printing Office, October, 1964.

U.S. Department of the Army. Materiel Development Management, FM 38-7. Washington: U.S. Government Printing Office, 1966.

_________ Army Programs, Program Evaluation and Review Technique (PERT), AMC Regulation Number 11-29, Washington: Army Materiel Command, 15 June 1966.

_________ Organization and Functions of USACDC Subordinate Commands, USACDC Pamphlet 10-1. Fort Belvoir, Virginia: U.S. Army Combat Developments Command, January 1967.

_________ Organization and Functions of Headquarters, USACDC, USACDC Pamphlet 10-2. Fort Belvoir, Virginia: U.S. Army Combat Developments Command, September 1966.

_________ USACDC Management Information System Procedural Guidance, USACDC Pamphlet 71-3. Fort Belvoir, Virginia: U.S. Army Combat Developments Command, April 1968.

_________ Contractual Scientific Support, USACDC Regulation 71-6. Fort Belvoir, Virginia: U.S. Army Combat Developments Command, May 1966.

_________ Methodology Notebook for Action Officers. Fort Belvoir, Virginia: U.S. Army Combat Developments Command, May 1967.

_________ Organization Mission and Functions Manual, USACDCICAS Regulation 10-1. Fort Leavenworth, Kansas: U.S. Army Combat Developments Command, Institute of Combined Arms and Support, December 1967.

_________ Readings in Command Management - General, Reference Book 20-5, Vol I. Fort Leavenworth, Kansas: U.S. Army Command and General Staff College, August 1967.

_________ Readings in Command Management, Modern Analytical Methods, Reference Book 20-5, Vol II. Fort Leavenworth, Kansas: U.S. Army Command and General Staff College, September 1967.

_________ CONUS Logistics and Combat Service Support, Reference Book 101-3, Fort Leavenworth, Kansas: U.S. Army Command and General Staff College, April 1967.

_________ Operations Research Appreciation. Rock Island, Illinois: U.S. Army Management Engineering and Training Agency, n.d.

Books

Abbott, Lawrence. Economics and the Modern World. New York and Burlingame: Harcourt, Brace and Company, 1960.

Ackoff, R. L., and Rivett, Patrick. A Manager's Guide to Operations Research. New York: John Wiley and Sons, Inc., 1963.

Churchman, C. W., Ackoff, R. L., and Arnoff, E. L. Introduction to Operations Research. New York: John Wiley and Sons, Inc., 1957.

Crowther, J. G. and Whittington, R. Science at War. New York: Philosophical Library, Inc., 1948.

Di Roccaferrera, Guiseppe. Operations Research Models for Business and Industry. Cincinnati: Southwestern Publishing Co., 1964.

Duckworth, W. E. A Guide to Operations Research. London: Metheun and Co., Ltd., 1962.

Friedman, Lawrence; Sasieni, Maurice; and Yaspan, Arthur. Operations Research Methods and Problems. New York: John Wiley and Sons, Inc., 1960.

Johnson, Richard A., Kast, Fremont E., and Rosenzweig, James E. The Theory and Management of Systems. New York: McGraw-Hill Book Co., Inc., 1963.

Jourdain, Philip E. B. The Nature of Mathematics reprinted in The World of Mathematics, Vol I. New York: Simon and Shuster, 1956.

Kast, F. E. Management in the Space Age. New York: Exposition Press, 1962.

Kaufmann, Arnold. Methods and Models of Operations Research. Englewood Cliffs, N. J.: Prentice-Hall, 1963.

McCloskey, J. F. and Coppinger, J. M. Operations Research for Management, Vol II. Baltimore: Johns Hopkins Press, 1956.

McCloskey, J. F. and Trefethen, F. N. Operations Research for Management, Vol I, Baltimore: Johns Hopkins Press, 1954.

Miller, David W. and Starr, Martin K. Executive Decisions and Operations Research. Englewood Cliffs, N. J.: Prentice-Hall, Inc., 1960.

Morse, Philip M. and Kimball, G. E. Methods of Operations Research, 1st ED. REV. Published jointly by the Technology Press of Massachusetts Institute of Technology and John Wiley and Sons, Inc. - New York, 1951.

Newman, James R. The World of Mathematics, Vol I. New York: Simon and Shuster, 1956.

Optner, Stanford L. Systems Analysis for Business Management. Englewood Cliffs, N.J.: Prentice-Hall, Inc., 1960.

Saaty, Thomas L. Mathematical Methods of Operational Research. New York: McGraw-Hill Book Co., Inc., 1959.

Shuchman, Abe (comp.). Scientific Decision Making in Business. New York: Holt, Rinehart and Winston, Inc., 1963.

Stockton, John R. Introduction to Business and Economic Statistics. Cincinnati, Ohio: Southwestern Publishing Co., 1966.

Weiner, Norbert. Cybernetics. New York: John Wiley and Sons, Inc., 1961.

________ Webster's New Collegiate Dictionary. Springfield, Mass.: G & C Merriam, Co., 1959.

Articles and Periodicals

Dix, James P. "Game-theoretic Applications," IEEE Spectrum, Volume 5, Number 4 (April 1968), 108-117.

Harling, John. "Simulation Techniques in Operations Research: A Review," Operations Research, (May - June, 1958), 307.

Hayes, James B., Col. "Systems Analysis," Army, (February 1964).

Weaver, Warren. "Probability," Scientific American, (October 1950), 44-46.

Reports

Fisher, G.H. The Analytical Bases of Systems Analysis, P3363. Santa Monica, Calif.: The Rand Corporation, May 1966.

Freeman, Raoul J. Developments for Modern Management, P-3210. Santa Monica, Calif.: The Rand Corporation, August 1965.

Goldstein, J.R. Scientific Aids to Decision Making, P1042. Santa Monica, Calif.: The Rand Corporation, March 1957.

Hitch, Charles. An Appreciation of Systems Analysis, P-699. Santa Monica, Calif.: The Rand Corporation, August 1955.

Hoag, Malcolm W. An Introduction to Systems Analysis, RM 1678. Santa Monica, Calif.: The Rand Corporation, April 1956.

Kahn, Herman and Mann, I. Techniques of Systems Analysis, RM-1829-1. Santa Monica, Calif.: The Rand Corporation, June 1957.

Kahn, Herman and Mann, Irving. Ten Common Pitfalls, RM 1937. Santa Monica, Calif.: The Rand Corporation, July 1957.

Klein, Burton and Meckling, William. Application of Operations Research to Development Decisions, P-1054. Santa Monica, Calif.: The Rand Corporation, April 1957.

Pettee, George S. The Decision-Making Problems of the Army. Chevy Chase, Maryland: Operations Research Office, December 1957.

Quade, E.S. Analysis for Military Decisions, R-387-PR. Santa Monica, Calif.: The Rand Corporation, November 1964.

Unpublished Material

Greyson, Murray (ed.). "Second War Gaming Symposium Proceedings." Washington: Washington Operations Research Council, 1964.

U.S. Department of the Army. Model for Management of the Life-Cycle of Materiel Systems. Washington: Approved by the Army Chief of Staff, 21 March 1967. (Ozalid copy available in Materiel Branch, Literature-Organization-Materiel Division, ICAS, Fort Leavenworth, Kansas).

________ USACDC Procedural Management Model, A Command and Staff Guide (DRAFT). Fort Belvoir, Virginia: 1968. (Xeroxed, ICAS, Fort Leavenworth, Kansas).

________ U.S. Army Combat Developments Command, Conceptual Management Model (DRAFT), undated, (Ozalid copy available in Materiel Branch, Literature-Organization-Materiel Division, ICAS, Fort Leavenworth, Kansas).

________ Letter, subject: Change in Term - "Army Concept Program." Fort Belvoir, Virginia: U.S. Army Combat Developments Command, 15 April 1968. (Xeroxed, ICAS, Fort Leavenworth, Kansas).

________ Informal Analysis of the Institute of Combined Arms and Support Master Model. (Typewritten, ICAS File Number 201-45, Fort Leavenworth, Kansas.).

________ Institute of Combined Arms and Support, Master Model, undated, (Ozalid copy available in Materiel Branch, Literature-Organization-Materiel Division, ICAS, Fort Leavenworth, Kansas.).

Other Sources

Dickson, Lee C., Lieutenant Colonel, U.S. Army, Materiel Branch, Literature-Organization-Materiel Division, Institute of Combined Arms and Support. Repeated interviews held during the period January - May 1968.

Moran, Homer B., Major, Branch "A", Doctrine Studies Division, Institute of Combined Arms and Support. Numerous interviews during the period January - May 1968

Neal, William B., Lieutenant Colonel, U.S. Army, Branch "A", Doctrine Studies Division, Institute of Combined Arms and Support, Numerous interviews held during the period January - May 1968.

Quirey, William O., Brigadier General, U.S. Army, Director of Studies, Office of the Vice Chief of Staff of the Army. A taped interview conducted in Kansas City, Missouri on 25 January 1968.

Seago, Pierce T., Jr., Major, Branch "A", Doctrine Studies Division, Institute of Combined Arms and Support. Numerous interviews held during the period January - May 1968.

Strohm, Hans W., Lieutenant Colonel, Chief, Analysis and Operations Research Support Branch, Evaluation Division, Institute of Combined Arms and Support. Repeated interviews held during the period January - May 1968.

Westlake, Wilfred J., Booz-Allen Applied Research, Inc. Operations Research Lecture delivered at the U.S. Army Command and General Staff College on 7 March 1968.